The Health of Compost Workers

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DECLARATION

I hereby declare that no part of this work has previously been submitted in support of an application for any degree or qualification at this, or any other Institute of Learning.

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Abbreviations

ABPA = Allergic Bronchopulmonary Aspergillosis

AD = Anaerobic Digestion

BM = Biological Monitoring

CFU = Colony Forming Units

COPD = Chronic Obstructive Pulmonary Disease

COSHH = Control of Substances Hazardous to Health

DECOS = Dutch Expert Committee on Occupational Safety

DEFRA = Department for Environment, Food and Rural Affairs

DNA = Deoxyribonucleic Acid

EA = Environment Agency

EAA = Extrinsic Allergic Alveolitis

ECHRS = European Community Respiratory Health Survey

EFA = Exploratory Factor Analysis

EPIDERM = Occupational Skin Surveillance Scheme

EU = European Union

FA = Factor Analysis

FEV_1 = Forced Expiratory Volume in 1 second

FVC = Forced Vital Capacity

IgE = Immunoglobulin E

IgG = Immunoglobulin G

IL = Interleukin

IOM = Institute of Occupational Medicine

HSE = Health and Safety Executive

HSL = Health and Safety Laboratory

IVC = In-Vessel Composting

LAL = Limulus Amoebocyte Lysate

MMI = Mucous Membrane Irritation

MOSS = Musculoskeletal Occupational Surveillance Scheme

MPN = Most Probable Number

NOS= Newcastle-Ottawa Scale

OA = Occupational Asthma

ODTS = Organic Dust Toxic Syndrome

OEL = Occupational Exposure Limit

OH = Occupational Health

OPRA = Occupational Physician Reporting Activity

ORG = Organics Recycling Group

OSSA = Occupational Surveillance Scheme for Audiological physicians

PCA = Principal Components Analysis

PPE = Personal Protective Equipment

PM = Particulate Matter

PRISMA = Preferred Reporting Items for Systematic Reviews and Meta-analyses

REA = Renewable Energy Association

RNA = Ribonucleic Acid

RPE = Respiratory Protective Equipment

SAFS = Severe Allergic Fungal Sensitisation

SIDAW = Surveillance of Infectious Diseases at Work

SIGN = Scottish Intercollegiate Guidelines Network

SOSMI = Surveillance of Stress and Mental Illness

SPT = Skin Prick Test

SWORD = Surveillance of Work-Related and Occupational Respiratory Disease

TB = Tuberculosis

THOR = The Health and Occupational Research

THOR-GP = The Health and Occupational Research network in General Practice

TNF = Tumour Necrosis Factor

VOC = Volatile Organic Compound

WEEE= Waste Electrical and Electronic Equipment

WEL = Workplace Exposure Limit

Preface

Waste recycling is a growing industrial sector. Drivers for growth include reducing emissions of greenhouse gases leading to climate change and resource sustainability. With this expansion however comes new workplace hazards and potential risks. Occupational health and safety challenges include the prevention of accidents and musculoskeletal injuries, as well as controlling workers' exposure to biochemical hazards.

Research in this area draws on theoretical frameworks in occupational, public health and environmental medicine, and in completing this work I am grateful to several individuals and institutions who have helped me gain a grounding in these disciplines, beyond those acknowledged directly in this thesis. I hope that in completing this work, I have done justice to those who have supported me through it, and to those who have kindly taken part. I hope that the participating companies and workers have found the process useful and rewarding. The findings are produced in good faith and should help inform policy and practice in this area.

Abstract

Introduction

Composting, otherwise known as green waste recycling, is a growing industrial sector. Whilst the environmental benefits of recycling activities are well-established, there is currently only a limited understanding of the potential adverse health effects of exposure to occupational hazards such as bioaerosols. It is thought that bioaerosol exposure may induce or exacerbate respiratory illness, but little is known about which components are responsible or which workers are most vulnerable.

Methods

A cross-sectional study examining the prevalence of respiratory symptoms in the UK industrial composting workforce was undertaken. Exposure studies were conducted at one indoor and one outdoor site to examine total microbial and fungal counts, as well as thermophilic bacteria and fungi present during agitative composting activities. A health questionnaire was subsequently administered to a volunteer sample of compost workers across six companies, who were also tested by skin prick test and blood for sensitisation to bioaerosol components and common aeroallergens. The questionnaire was evaluated using a principal component analysis (PCA).

Results

Exposure measurements confirmed the sites were ones in which workers had bioaerosol exposure consistent with that observed previously in the industry. Workers reported symptoms including rhinitis, conjunctivitis, cough, wheeze and shortness of breath. Workers with more than 10 years in the industry had a higher prevalence of ocular irritation. No differences were seen according to site type (indoor/outdoor), *Aspergillus* sensitisation status, or whether workers were mono or polysensitised by IgE to any of the aeroallergens tested in the study. The PCA condensed the questionnaire from 46 to 37 items.

Conclusion

The higher prevalence of ocular symptoms in those workers having been in the industry for more than 10 years is of concern for which the implications merit further study. These include the progression to clinical disease affecting the lower airways and wider systemic disease. Findings from this study do not suggest that those workers sensitised to *Aspergillus fumigatus* or other aeroallergens reported more symptoms, but further inferences are limited by the cross-sectional design.

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Finally, the companies and workers that agreed to take part in the project.

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Chapter 1: Introduction

Occupational medicine is concerned with the bidirectional relationship between work and health. This may involve individuals, groups of workers or examine the effects of workplace activities on the surrounding population. Perhaps uniquely in medicine, occupational health practitioners have obligations to workers as well as third parties which may include employers, trade unions or legal representatives. Research in this field should acknowledge such responsibilities, and an appreciation of the political, environmental, social and technological factors.

The first part of this thesis will focus on how these issues relate to waste recycling by discussing scientific matters related to waste generation and the technology of waste management. Following a description of the known and theoretical health hazards in the major waste recycling sectors, I shall discuss the scientific basis of compost production, which is needed to understand how bioaerosols, also commonly called organic dusts, are generated. I shall then describe the immunobiology of bioaerosols and the health effects that are known to or suspected to arise from bioaerosol exposures using evidence from community and occupational health studies. Finally, I shall describe existing control measures to reduce or eliminate compost workers' exposure to bioaerosols.

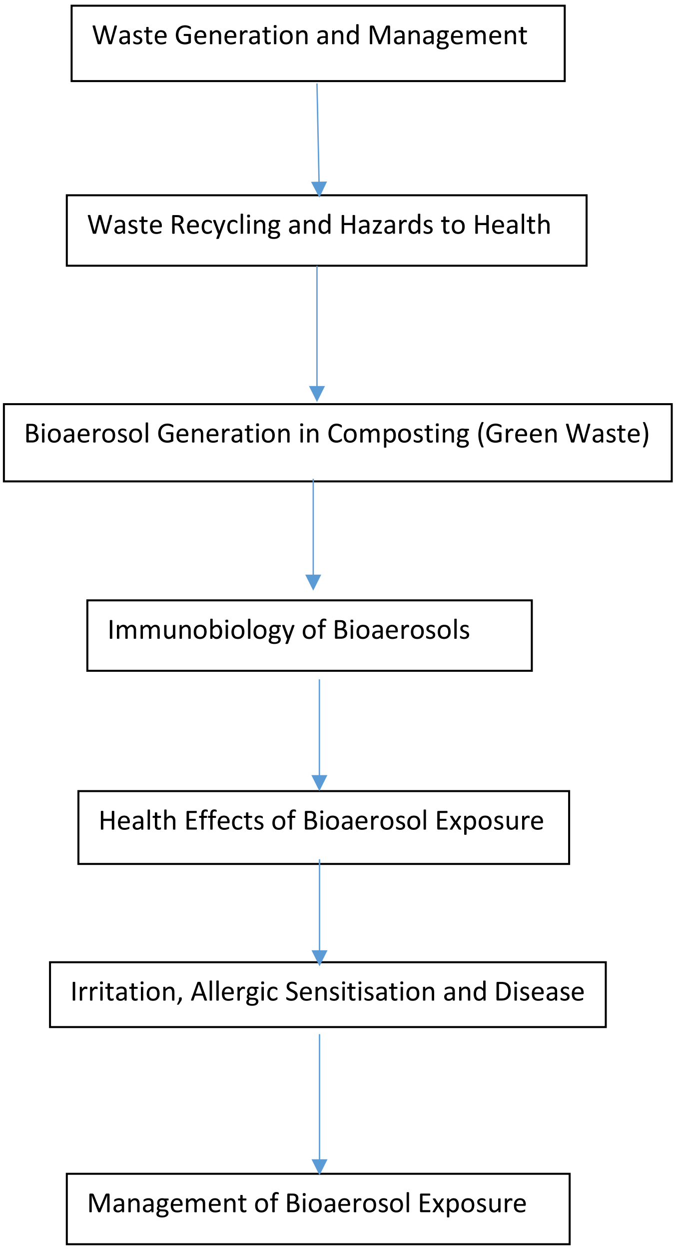


Figure 1: Structure of Introduction Chapter

1.1. Waste Production

Waste is defined by the European Union (EU) Directive 2008/98/EC as *'any substance or object which the holder discards or intends or is required to discard*.' Increasing waste production; concerns over the sustainability of resources, rising demands for energy and goods particularly from developing countries, a move to reduce landfill waste, and the environmental, social and political consequences of rapid climate change are levers that currently drive waste management policy.

Consequently, there have been international efforts to increase the amount of recycled waste, informed by several global datasets about waste production. These include the United Nations Statistics Division questionnaires on Environment Statistics Waste Section; Organisation for Economic Co-operation and Development Environmental Data Compendium and the United Nations, Department of Economic and Social Affairs, Population Division and Eurostat Environmental Data Centre on Waste.

Municipal waste originating from households, businesses and institutions such as schools and hospitals is thought to account for only 10% of total waste production, but it is of interest because of its presence in many forms of waste, its complex composition and association with consumption patterns. The most recent international data on municipal waste collection covers the years 2005 to 2009 (United Nations Statistics Division 2011). Whilst the highest total amounts are collected in the United States (222853 thousand tonnes in 2005) and China (157340 thousand tonnes in 2009); Antigua, Belize, Singapore and Malaysia outstrip both countries in terms of the amount of waste collected per head of the population.

European data indicates that waste generation per capita has increased in 17 out of 31 EU nations between 2004 and 2017; with only 12 showing a decline during this period (Eurostat 2017). The figure below displays total waste generation in the European

Union in 2016 by country of origin. The highest levels of European municipal waste generation per capita in 2017 were recorded in Denmark, with a 46% increase since 1995. Whilst the degree of coverage provided by collection services is limited, these data do provide some insight into the scale of the waste generation problem.

Figure 2: EU Waste Generation 2017 (courtesy of Eurostat, publicly available)

The figure identifies that the highest recorded amounts of waste in the European Union are produced by Denmark, Norway and Switzerland, whereas the lowest are found in Poland and Romania.

1.1.1. Waste Management Policy and Strategies

Evidence suggests that EU Directives such as a target for the United Kingdom (UK) to recycle at least 50% of household waste by 2020 and the Europe 2020 strategy, of which one goal is to reduce greenhouse gas production by 20% from 1990 levels, are influencing recycling policies in member states. For example, the Department for Environment, Food and Rural Affairs (DEFRA) in the UK has developed a hierarchy of waste management preferences, shown in the figure below. The preferred tier involves the reduction of waste production at source followed by materials recovery, composting, incineration with energy recovery and finally disposal to landfill (DEFRA 2011).

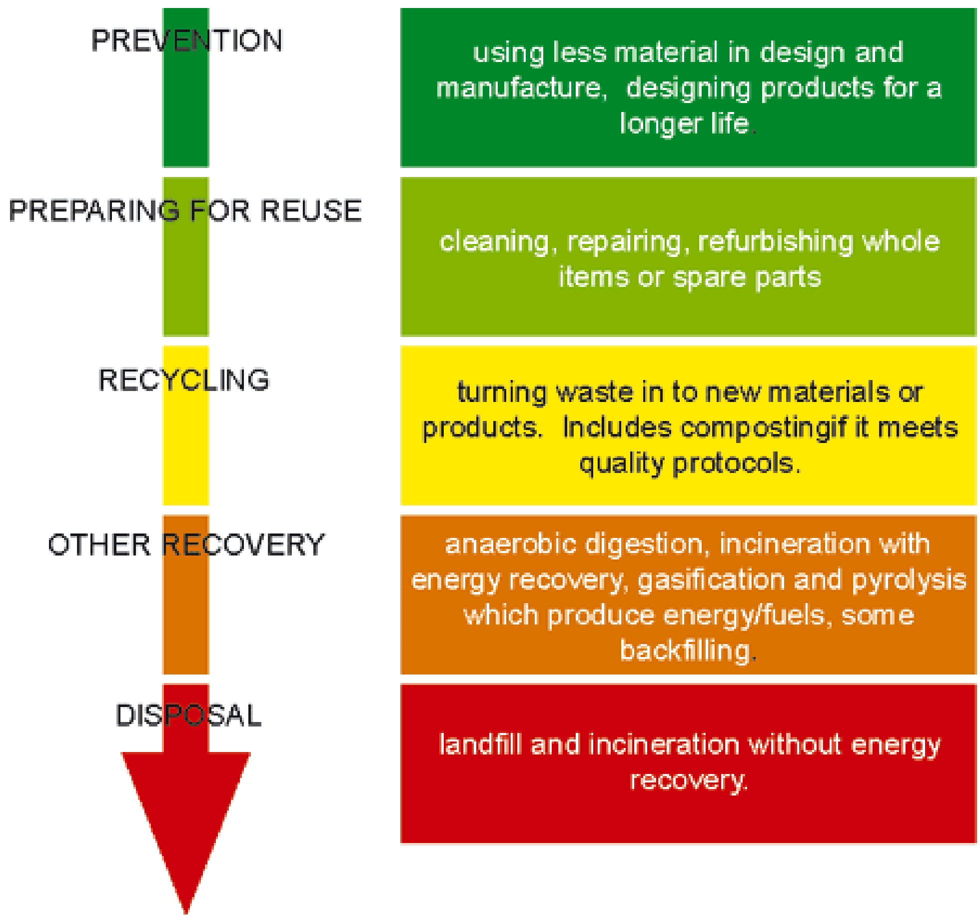


Figure 3: DEFRA Waste Management Hierarchy (courtesy of DEFRA, publicly available)

DEFRA has introduced a hierarchy of controls beginning with the prevention of waste generation, reuse, recycling and extraction of materials, followed by landfill and extraction as the least preferred approach.

Policy changes have influenced recycling and material recovery practices in recent decades. The total amount of municipal waste sent to landfill across the EU-27 nations has dropped by 54% from 144 to 66 million tonnes in the last 20 years (Eurostat 2016). Accordingly, there has been an increase in EU municipal waste sent to recycling facilities to 66 million representing an increase of 166% from 1995 levels. Nonetheless, the amount of waste incinerated has doubled from 32 million tonnes in 1995 to 64 million tonnes in 2014.

In the UK, DEFRA statistics indicate that about 45% of household waste was recycled in 2015 (DEFRA 2015). There is considerable variation in recycling practice across the UK, with Wales at 55% of all recyclable materials, higher than the average of other UK nations which is at 44%. This may be in part due to Wales' landfill allowance scheme which requires waste disposal authorities to limit the amount of municipal waste sent to landfill. Other suggested reasons for this difference include more consistent practice towards the sorting and handling of waste, with a greater array of recycling bins available at household level (DEFRA 2015). This difference has raised the question whether similar strategies should be developed in England, Scotland and Northern Ireland.

1.2. Waste Recycling Sectors

The waste recycling sector employs over 100,000 workers in the UK, with seven major companies accounting for approximately 40% of the industry's £11 billion annual turnover and the remainder accounted for by small and medium sized local enterprises. The main waste recycling sectors include:

- Composting, Municipal Solid Waste and Hazardous waste
- Metal, Batteries, Cables and Wires
- Glass and Fluorescent Lights
- Landfill
- Textiles
- Wood
- Medical Waste
- Paper and Nappies
- Waste Electrical and Electronic Equipment (WEEE)

Certain processes are common to all sectors including waste collection; reception of waste materials at the recycling plant; waste sorting, processing and recovery of resources; biological, chemical or thermal treatment of materials, and disposal of remaining waste. Each process is associated with known or suspected health hazards and these vary according to the materials being recycled.

Across all recycling sectors in the UK, fatal and non-fatal injuries have been of concern. The prevalence of fatalities reported under the Reporting of Injuries and Diseases and Dangerous Occurrences Regulations (RIDDOR) scheme run by the Health and Safety Executive (HSE) was 3.64 per 100000 employees in 2014/15, which compares with 0.48 per 100000 employees for all UK industries (HSE 2015). Non-fatal injuries are commonly reported in the recycling sector. Mechanisms involved include slips and trips; falls, being struck by moving vehicles or machinery and contact with hazardous substances. Whilst these data are potentially subject to reporting bias, they provide an insight into the potential dangers of working in this industry.

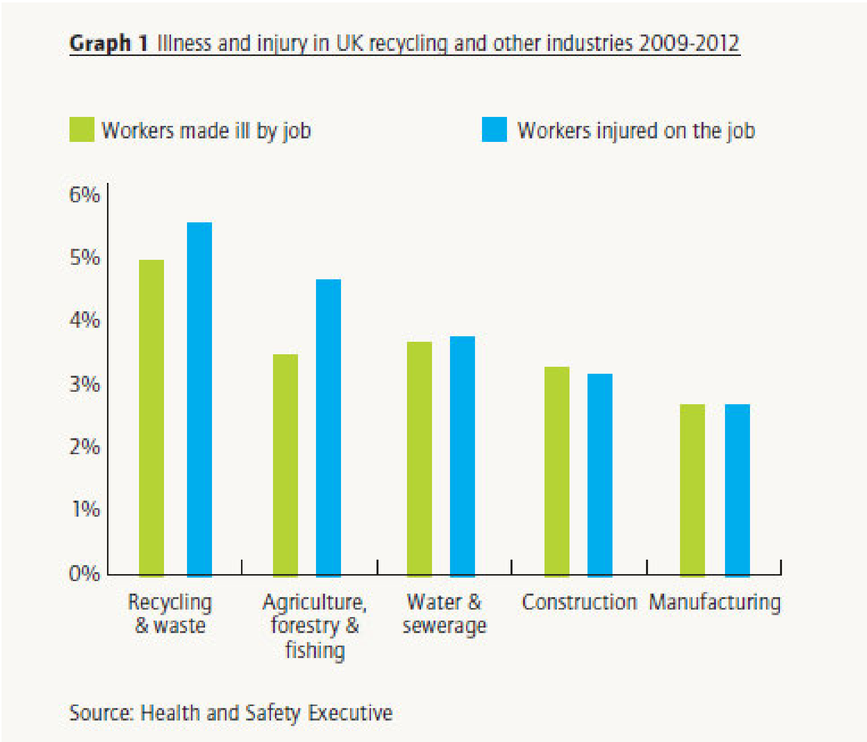


Figure 4: Non-fatal injury and illness in the UK recycling sector HSE Statistics 2009-2012 (publicly available)

Data recorded by the Health and Safety Executive from RIDDOR reports, indicates that percentages of non-fatal work-related illness and injury are highest in the waste & recycling sector, outstripping industries such as construction and manufacturing.

The following section discusses known or suspected health hazards by recycling sector, apart from composting (green waste) recycling which will be discussed in more detail later.

1.2.1. Health Hazards by Recycling Sector

In this section, I shall outline the main occupational hazards and risks to human health that have been identified in the waste and recycling industry. These will be grouped according to the sectors shown below in Table 1. A structured, systematic review of hazards in the composting sector is found in the results chapter, whereas a narrative discussion for other sectors is found here. To inform this discussion, I examined a number of databases using key search terms with the support of Miss Victoria Wollerton, a professional librarian at the Health and Safety Laboratory. The following databases were examined; Web of Science, Medline, Embase, Health and Safety Science Abstracts, Osh Update, e-library and Google Scholar.

Major Waste & Recycling Sectors

1. Composting, Municipal and Domestic Solid Waste
2. Metal, Automotive, Batteries, Cables and Wires
3. Glass and Fluorescent Lights
4. Landfill, Textiles and Wood
5. Medical Waste, Paper and Nappies
6. Waste Electrical and Electronic Equipment

Table 1: Major Waste & Recycling Sectors

Municipal and Domestic Solid Waste

Municipal waste workers not exposed to compost may be exposed to other hazards from incinerator waste such as heavy metals, polychlorinated dioxins, dibenzofurans, polycyclic aromatic hydrocarbons and particulate matter. Cross-sectional studies of hazardous waste incinerator workers showed mean concentrations of heavy metals, polychlorinated dioxins and PCBs in blood or urine to be no different from controls in newer incinerators (Schuhmacher et al 2002; Mari et al 2007; Mari et al 2013; Yamamoto et al 2015). Similar studies have been undertaken of residents living near a solid waste incinerator in Portugal, but no significant differences were found in blood levels of heavy metals and dioxins compared with controls (Fatima et al 2007). Exposure to solvents in paint has been noted as another potential hazard, but no cases of occupational illness from this were found. There is no evidence from the literature currently that these exposures cause illness, but further work may shed more light on this issue.

Metal, Automotive, Batteries, Cables and Wires

The main reported hazard in this sector is exposure to heavy metals, particularly lead when torch cutting metal plate and from lead-acid battery recycling (Huo et al 2007). Dioxin exposure has been noted from melting scrap metals, especially aluminium (Sweetman et al 2004). A case report identified raised blood lead in children living near or working in lead-acid battery recycling factories and being fatally or sub-clinically poisoned with lead (Liu et al 2011). Children of metal or battery recycling workers were also found to have raised blood lead from dust carried home on their parents' clothing (Newman et al 2015). There is one case report from Italy of a worker recycling lead-acid batteries developing anaemia and polyneuropathy due to lead poisoning (Fonte et al 2007). Urinary mercury in excess of the Biological Exposure Index was also reported in alkaline battery recycling workers (Reh et al 2001). Four factories in the USA that recycled lead-sheathed copper telephone cables were closed after workers were found to have high concentrations of blood lead (Lax et al 1996). There is a report of radioactive material being found amongst scrap metal and of radioactive material getting into the finished product (Lubenau & Yusko 1998). Exposure to dioxins from the thermal degradation of printed circuit boards was also reported, but no health effects (Guo et al 2015).

Glass and Fluorescent Lights

Several adverse health effects have been associated with working in this sector. One cross sectional study reported increased nasal and chest symptoms from presumed fungal and particulate exposure in glass recyclers (Shanks 2008). There was one case report of raised blood lead in a worker and his two children from the recycling of cathode ray tubes which were made from leaded glass and contain lead in the funnel glass (Newman et al 2015). In the recycling of fluorescent lights there is potential for exposure to mercury vapour and to dust containing lead and yttrium. There was a case report of two workers from a fluorescent tube recycling factory in Germany, one with membranous glomerulonephritis and the other with nephrotic syndrome due to mercury poisoning (Aymaz et al 2001). There was also reference to a case of chronic mercury poisoning in a glassblower in a fluorescent lamp manufacturer in the UK (Guthrie et al 2006).

Landfill, Textiles and Wood

The main known or suspected hazards from landfill are inorganic dust, bioaerosols, asbestos and truck exhaust emissions. There were two cross-sectional studies from the USA reporting increased skin, respiratory, throat and gastro-intestinal symptoms in landfill workers (Gelberg 1997; Kitsanas et al 2000). Raised total serum IgE levels were also found in landfill workers, but these levels did not correlate with symptoms. The sorting and shredding of fabric for recycling may be associated with high exposures to cotton dust and endotoxin (Paudyal 2010). Textile workers may experience rhino-conjunctivitis and respiratory symptoms on the first day back at work which improves with persistent exposure throughout the working week (byssinosis). Symptoms may persist throughout the week and may lead to chronic lung disease. Cross-shift falls in FEV_1, non-specific bronchial hyper-reactivity and an accelerated longitudinal decline in FEV_1 have been reported in two studies (Christiani et al 2001; Paudyal et al 2015). High concentrations of dust more than the Workplace Exposure Limit of 5 mg/m^3 and of airborne micro-organisms, particularly fungi and bacterial endotoxins have been measured in wood (including fibreboard and chipboard) recycling factories, particularly during shredding and cleaning processes, or storing wood chips. Nonetheless, there were no reports of occupational illness. Irritant-induced asthma has been reported in three workers in a wood burning waste facility in Germany (Arendrup et al 2006) and two cases of acute pulmonary aspergillosis on exposure to bark chippings (Preisser et al 2010).

Medical Waste, Paper and Nappies

The main hazards for medical waste handlers are sharp injuries and exposure to blood or blood-stained materials. Pathogenic infections, toxic chemical and radioactive materials are other potential hazards. Blood splashes to the face have been reported in workers handling medical waste, but there were no reports of occupational infections from this source. For paper recycling, other than the potential consequences from manual handling, the recycling of clean, dry paper does not appear to be hazardous. Paper or cardboard stored damp, or if contaminated with organic material such as faeces could plausibly be associated with elevated bacterial and fungal exposure. There was one cross sectional study of increased respiratory symptoms, increased inflammatory markers in serum and increased methacholine bronchial reactivity in paper workers (Rylander et al 1999); one case report of occupational asthma due to hydroxylamine used for 'de-inking' in a paper recycling factory in the UK (Tran et al 2009) and an abstract reporting increased sensitisation to storage mites in recycling paper-mill workers (Kanceljak et al 1997).

Waste Electrical and Electronic Equipment (WEEE)

This recycling sector includes white goods, telephones, televisions, printed circuit boards and printers. Most of the research has come from China. The main hazards in this sector, apart from heavy manual handling, were exposure to heavy metals such as copper, silver and gold; dioxins, furans and polycyclic aromatic hydrocarbons. Raised serum levels in workers of copper, cadmium, lead, cobalt, mercury, polycyclic aromatic hydrocarbons and platinum from catalytic converters have been identified (Caravanos et al 2013). Chromosomal aberrations and DNA damage have also been reported (Grant et al 2013). Exposure to polybrominated diphenyl ethers (a flame retardant) and raised levels in the blood of workers have been found in WEEE recyclers (Schecter et al 2009). Exposure to chromium has been linked to abnormal lung function in children and neonatal defects to include stillbirths, premature births and low birth weights (Song 2015). There was one case report from the USA of argyria in an X-ray and photographic recycler (Gwin & Nemhauser 2000).

Cases from UK's Surveillance Schemes

Four cases of occupational asthma, two of Q fever, two of leptospirosis, one of extrinsic allergic alveolitis, one of contact dermatitis and a cluster of lead poisoning were noted from HSE's Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR). Some of these cases led to enforcement action against the employer. There was no information about the evidence for diagnosis or attribution. The THOR network, based at the University of Manchester, identified 371 cases of work-related illness diagnosed by a doctor in the waste and recycling sector between 1989 and 2015. This corresponds with an estimated incidence of 1504 cases (personal communication). For the Occupational Physician Reporting Activity (OPRA) most cases in this sector were musculoskeletal involving the back and upper limbs to include injuries, fractures, epicondylitis and tenosynovitis, but there were also cases of contact dermatitis, asbestos related lung disease, Q fever, leptospirosis and three fatalities from toxic gas. For the surveillance of Work-Related and Occupational Respiratory Disease (SWORD) most cases were of asbestos related lung disease and asthma due to exposure to dust, bioaerosols and chemicals such as isocyanates, solvents and methane. For the occupational skin surveillance scheme (EPIDERM) most cases were of contact dermatitis due to irritants to include oils and solvents, or sensitizers in gloves such as thiurams, mercapto mix and chromates, as well as neoplastic disease from sunlight. For the occupational health reporting network for general practitioners (THOR-GP) and the musculoskeletal occupational surveillance scheme (MOSS) most cases were musculoskeletal from heavy manual handling but included one case of lead poisoning. For the surveillance of stress and mental illness (SOSMI) there were cases of anxiety, depression and post-traumatic stress disorder. The surveillance of infectious diseases at work (SIDAW) identified diarrhoeal disease and leptospirosis and noise-induced hearing loss (OSSA).

Summary

Workers in the metal, battery and cable recycling sector may be exposed to heavy metals to include lead, mercury, copper and cobalt. Raised blood lead concentrations in workers and in their families, have been reported. This reinforces the importance of workplace controls and personal hygiene. For UK workers, The Control of Lead at Work Regulations 2002 will apply to many of these workplaces for which biological monitoring will be required. Whether this should be undertaken for other heavy metals will be determined by either a need for health surveillance where cases of ill health have been detected, or where there is a need to know if workers are being significantly exposed to these metals by way of dust or fume. Some health effects might be unexpected such as mucosal membrane irritation from microbiologically contaminated glass or raised blood leads from the recycling of cathode ray tubes, or nephropathy due to mercury exposure from the recycling of fluorescent lights. Wood and paper recycling have both been associated with occupational asthma and exposure to tree bark with acute bronchopulmonary aspergillosis (ABPA). Although the main hazards of glass recycling are probably excessive noise from the tipping of glass and ergonomic problems when boxes of glass are manually handled, there are little data on these issues in the published literature.

Table xxxxx in the Appendix outlines suggestions for what health surveillance to consider in these sectors of the waste and recycling industry. A risk assessment with occupational health input in conjunction with the findings in this section should help management with decision making. The remainder of this thesis will focus on the composting (green waste) recycling sector, beginning with a discussion of the science of composting and the different approaches to composting activity.

1.3. Composting

1.3.1. The Science of Composting

Haug (1993) defines composting as the "*controlled biological decomposition and stabilisation of organic substrates, under conditions that are predominantly aerobic that allow the development of thermophilic temperatures as a result of biologically produced heat, to produce a final product that is stable, free of pathogens and plant seeds, and can be beneficially applied to land*". Industrially composted organic materials include pine needles, grass, food waste, garden refuse, straw, manure, wood, paper, seaweed, mushroom and sewage. The modern Indore method of composting developed by Sir Albert Howard involves laying piles of green matter upon a brush-base layer up to a height of approximately five feet and turning them at six-weekly intervals.

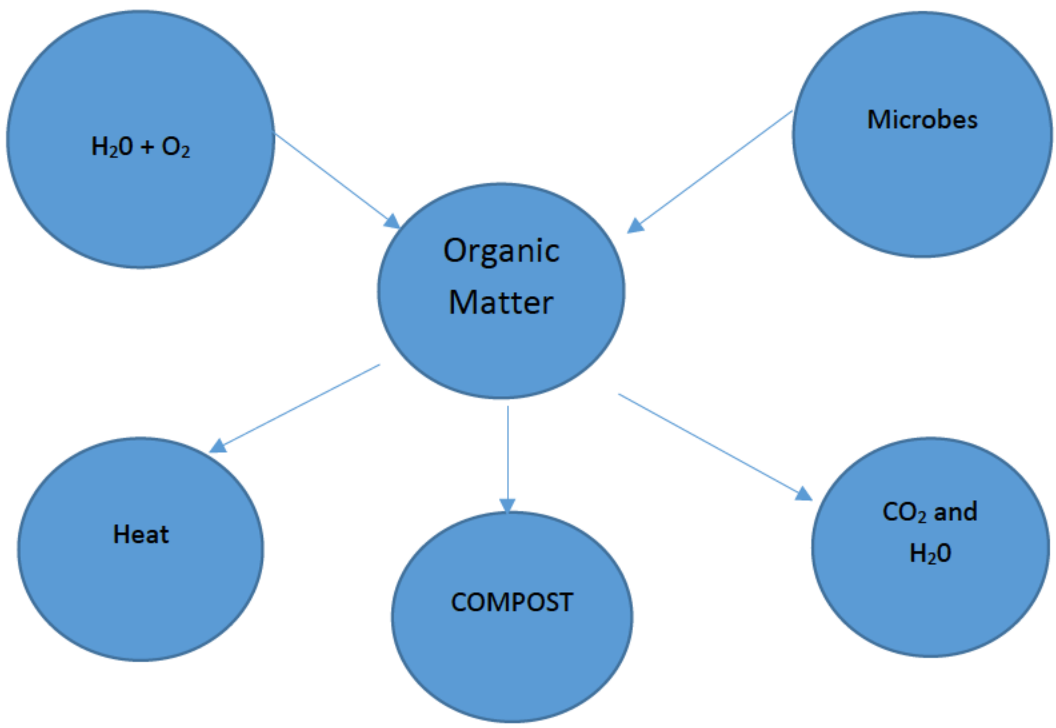


Figure 5: Overview of the Composting Process

Figure above illustrates that the mixture of organic matter, microbes, water and oxygen produces an exothermic reaction resulting in the formation of compostable material.

A mix of water, oxygen, micro-organisms and organic matter produces compost. An optimal ratio of oxygen concentration, moisture, temperature, nutrient factors such as carbon and nitrogen and pH promote microbial activity and cell synthesis. Stentiford (1996) outlines the major processes involved in composting waste which are sorting, shredding, turning and screening. Sorting involves separating material suitable for composting such as food and green waste from other materials. Shredding reduces particle size so that the surface area to volume ratio is increased allowing for higher speeds of decomposition. The frequency of turning depends on the desired ratio of co-factors such as the moisture content, oxygen concentrations, pH and carbon-to-nitrogen ratios, and is usually performed at 6-12 weekly intervals. Turning aerates the compost by introducing fresh air and releases trapped moisture, heat and stale air. Cooler and warmer portions of the compost pile are also redistributed hence helping to maintain thermophilic temperatures. Smaller sites in the UK use tractors with a front-end loader or grab to pick up piles of compost which are emptied at a new site, thus reforming a new windrow. Larger sites may use more specialised machinery to turn the composting material. Bishop & Godfrey (1983) described the relevance of the carbon: nitrogen ratio in producing compost, indicating this should be 30:1. Too low a ratio leads to the volatilisation of nitrogen to form ammonia. Too high a ratio leads to a depletion of available nitrogen for microbes resulting in reduced cellular growth and cell death. Epstein et al (1997) stated that the optimal pH for compost is between 6.5 and 9.6, as in this range the highest temperatures (>55 ^{O}C) are maintained for the longest period. It has been established that the optimum moisture content for composting is between 50-60%. Microbial activity decreases at levels below 40% and anaerobic conditions develop at moisture levels above 60% (Poincelot, 1974). Composting temperatures are stratified into mesophilic (<45 ^{O}C) and thermophilic (>45 ^{O}C). Most literature suggests that the optimum temperature for composting is between 50 to 60^{O}C (Epstein 1996) and may need to be maintained for several days if there is a need to disinfect waste. Deportes et al (1997) estimated that one hour at 68

^{O}C will kill most pathogens such as *Salmonella spp., Escherichia coli* and *Shigella spp*. Finally, screening involves feeding the cured compost usually into a cylindrical drum rotating on an axis. Small contaminant particles are filtered from the compost to produce the final product, such as the bags of compost commonly sold at garden centres.

Image 1: Shredding (left) and Screening (right) of compost

Shredding of compost involves breaking up large amounts of green waste into smaller components which can be transferred to a composting pile such as an open windrow. Screening involves passing material through a fine sieve to produce the final material.

Miller (1994) suggested an alternative classification for the composting process including thermophilic, cooling and stabilisation phases. The first *'thermophilic'* phase involves an increase in temperature during which organic material is degraded first by mesophilic and then thermophilic species as temperatures rise above 45 ^{O}C. The second *'cooling'* phase involves the destruction of pathogenic micro-organisms at temperature above 50 ^{O}C. Temperature reduction in the final *'stabilisation'* phase encourages the growth of mesophilic organisms (*Actinomycetes spp*. and some fungi) which breakdown lignins to produce the final compost.

1.3.2. Modern Approaches to Composting

There are four main approaches used by industry to compost waste (Swan et al 2003) of which the open, outdoor system is the most widely used. In this approach, organic waste is laid in long piles known as 'windrows'. Stagg et al (2010) indicated that to control production of offensive odours, garden waste rather than food waste is generally used, whereas both may be more commonly found in other forms of composting.

Image 2: Open-Windrow Compost Piles

The image shows four open windrow compost piles lying parallel to each other. The piles are approximately 10-12 feet high and pyramid-shaped. The piles are turned at frequent intervals (once a week for a 6 to 12-week period) to maintain optimum conditions. Probes are placed in the piles to measure pH, temperature and moisture content.

The second form of industrial composting is the use of passively-aerated static windrow piles. Rather than 'actively' turning material using mechanical systems as in open-air windrow composting, these systems supply air to each windrow through perforated pipes running beneath them. The pipe-ends are open, thus supplying air via convection. The aerated static pile method takes this a step further by using a forced mechanical system to supply air to the compost. This may either be a 'blowing' (positive aeration) system to drive air through the compost, or a 'suction' (negative aeration) system to draw air through the piles. The compost is laid over a porous material, such as wood chips or fine straw to optimise aeration. Swan et al (2003) noted that one advantage of this system is that active aeration allows for the creation of higher piles which helps retain heat in the compost.

Enclosed rather than open systems may also be used to compost organic material, commonly known as "In-Vessel Composting" systems (IVC). These vary in size from small scale containers to large enclosed halls. *Bin composting* is the simplest form of IVC system. These operate in a comparable way to passively-aerated windrow systems by supplying air through perforations in the floor of the bin. *Tunnels* operate in a similar manner to bin IVC systems but are larger and more developed. Some sites may use mechanical means to agitate the compost. A third type of IVC is the *agitated bed system* where there is periodic turning of rows of compost laid in rectangular beds by machines which run along the length of the walls separating them. Forced aeration may also be provided through floor ducts. The beds are generally enclosed in a building or greenhouse to protect composting equipment and control conditions. A variation on this approach is the use of *enclosed halls* in which compost material is spread in one long bed across the floor of the hall. Large bucket wheels are used to turn and move the compost through the system (Edwards 2004). A fifth in-vessel technique is that of a *bottom-unloading silo.* A mixture of raw materials is loaded at the top and is composted as they pass down the silo, eventually unloaded at the bottom using an augur. An aeration system blows air up from the base of the silo through the composting materials. The proportion of compost removed from the silo must be replaced each day, so for example if a process takes two weeks; one-fourteenth of the silo volume must be removed and replaced daily. The stacking however introduces compaction, temperature control and air flow challenges, and materials therefore must be well-mixed when entering the silo. Finally, the sixth form of IVC is the use of large rotating cylinders known as *rotating drums*. These drums mix, aerate and move the compost material through the system. They may hold up to 50 tonnes and, as with the silo IVC process, new feedstock can be introduced at the top of drum daily. The speed of the drum and the axis of rotation are important determinants of composting time.

Image 3: Compost piles in an In-Vessel facility

Compost piles are arranged parallel to each other in a large enclosed hall and turned at frequent intervals in this in-vessel facility. Once again, environmental conditions are closely monitor. In some IVCs air is forced into the piles through a positive pressure system lying under the floor of the hall.

Vermicomposting is a fourth category of composting which involves an interaction between certain species of earthworms and microorganisms to fragment, mix, oxidise and stabilise the organic waste. In this process, there is no requirement to mix or aerate the compost mechanically. Vermicomposting is usually carried out in windrows or in bin systems but at temperatures no greater than 35 ^{O}C. The process has been extensively used in processing wastewater and material from the brewery, potato, paper and mushroom industries (Domínguez 2004). Finally, there are some parallels between composting processes and that of anaerobic digestion (AD). The latter is essentially also a form of in-vessel digestion and the digestate produced from the process may also be used as compost (Cheng et al 2008).

1.3.3. Bioaerosols in Compost – Nomenclature and Recorded Emissions

'Bioaerosols' are defined as naturally occurring particulates that are suspended in the ambient environment of microbial, plant or animal origin, a term often used synonymously with organic dust (Douwes et al 2005). Several bioaerosol components produced during the composting process may cause respiratory health problems. Exposure to fungi and bacteria during the composting process may occur through whole or fragments of living and dead organisms; structures produced by the organism such as fungal spores, or derived from them such as endotoxins, glucans and mycotoxins.

In keeping with the science of composting, it follows that certain micro-organisms predominate at different stages of the process. For example, during the screening of fresh green waste at the start of the cycle, organisms such as *Alternaria alternata* and *Cladosporium herbarum* are most prevalent, since these thrive in such outdoor, cool environments (Achatz et al 1995). *Penicillium chrysogenum* has also been found in compost but is known to be more prevalent in indoor environments (Swan et al 2003). The heating process should destroy such organisms, and thus organisms such as *Aspergillus fumigatus* and the species of *Actinomycetes spp.* (*Saccharopolyspora rectivirgula*, *T. vulgaris, T. viridis, T. sacchari)* dominate the microbiological mix in the thermophilic phase. Potential adverse health effects from exposure to these thermophilic organisms has led to concern in the medical community and composting industry. The rationale for this is described in later sections.

In a review article, O'Gorman (2011) stated that background environmental concentrations of *A. fumigatus* are generally below 10 cfu/m^3 but may spike at 400 cfu/m^3 in the autumn and winter. In contrast, measured concentrations of total bacteria within 1000 metres of compost facilities have ranged from 10^2 - 10^5 cfu/m^3, which are substantially higher than those from domestic garden compost piles. A systematic review of workers' bioaerosol exposures conducted by Pearson et al (2015) reported that *A. fumigatus* concentrations have generally ranged between 10 to 10^4 cfu/m^3. Taha et al (2006) however identified elevated bioaerosol concentrations during compost agitation activities, with exposures up to 10^7 cfu/m^3 for total bacteria and 10^6 cfu/m^3 for *A. fumigatus* respectively. Concentrations of *Actinomycetes spp.* spores emitted from composting activities have varied, perhaps in part due to different measurement methods. In Finland, maximal concentrations of live spores of 20 x 10^3 cfu/m^3 have been recorded in comparison to 3500 x 10^3 cfu/m^3 at German waste recycling sites (Tolvanen et al 2005) (Bunger et al 2007). Using personal sampling, Heldal et al (2015) measured maximal concentrations of 5.6 and 590 x 10^6 spores/m^3 of *Actinomycetes spp.* in a Norwegian outdoor windrow and indoor waste processing site respectively. This suggested indoor waste workers may exposed to higher concentrations of these bacteria. Nonetheless, it was noted by the authors that the prevalence of respiratory symptoms was paradoxically higher in outdoor workers, perhaps due to the wider use of respiratory protective equipment in the indoor facility.

Other bioaerosol components in compost may be of relevance to health. Endotoxins (lipopolysaccharides) are released from the outer membrane of damaged Gram-negative bacterial cell walls. They are composed of a combination of polysaccharide chains, a lipid unit responsible for the toxic effects in cells and a connecting core unit (Duquenne et al 2013). They are found extensively on the surfaces of organic material such as animals, plants and soil as well as in human and animal nasal cavities. These may become airborne, particularly in activities that agitate compost. Other biologically active substances which may be released from Gram-negative bacterial cell walls include lipopeptides, which are a class of molecules consisting of one or more lipid chains attached to a peptide headgroup. Gram-positive bacterial cell walls consist of a single lipid bilayer (as opposed to the double lipid bilayer of Gram-negative bacterial cell walls) and a thick but permeable layer of peptidoglycan, a chain of polysaccharides (ß-1,4-linked N-acetylglucosamine) and N-acetylmuramic acid, connected by short peptides. Fungal cell walls are composed of polysaccharides such as chitin, mannan and beta (β)-glucan. Certain β-glucans have received interest in the scientific literature such as pleuran and lentinan from mushrooms for their anticarcinogenic properties (Rop et al 2009). Other however have been associated with adverse respiratory health effects, such as those from *Aspergillus spp*. (Sykes et al 2011).

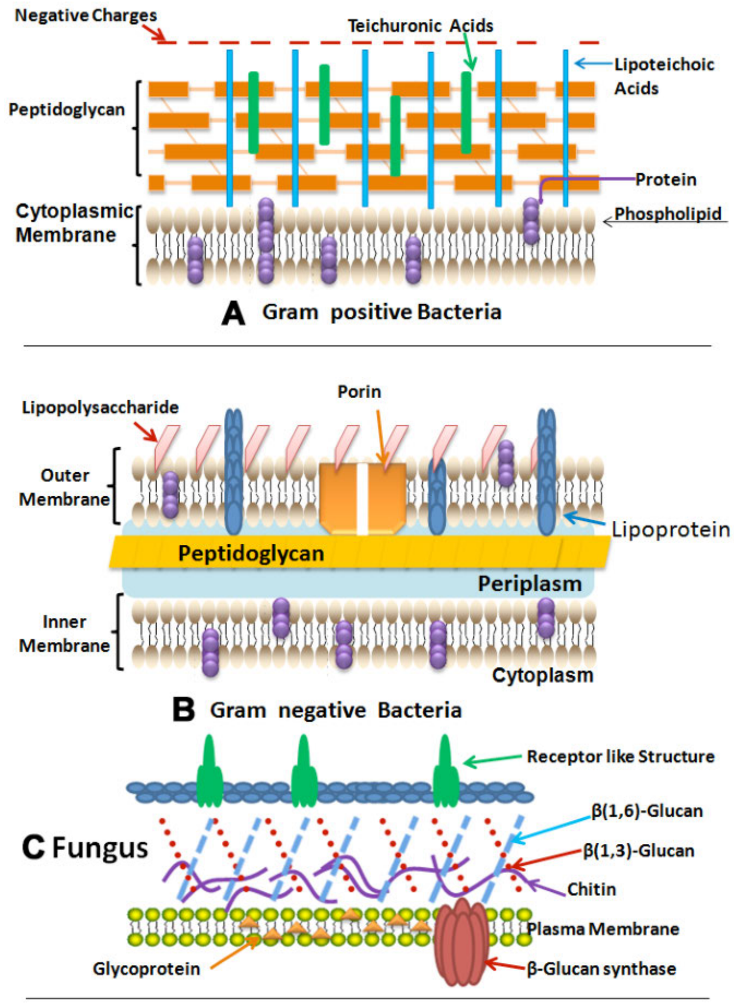


Figure 6: Illustration of Bacterial and Fungal Cell Walls
(reproduced from Kashef et al 2017 with no modifications)

The cell walls of Gram-positive bacteria are composed of a thick layer of peptidoglycan and a single phospholipid layer in contrast to the double lipid layer of Gram-negative bacteria with lipopolysaccharide (endotoxin) and lipoprotein. Fungal cell walls consist of isomers of (β) -glucan, chitin, mannan and dectin.

Other relevant dust components include particulate matter (PM) and volatile organic compounds (VOCs) such as oxides of carbon, nitrogen and ammonia which have irritant properties. Particulate matter (PM) has received attention for its role in cardiovascular, circulatory and respiratory disease, primarily through exposure to traffic exhaust emissions (Raaschou-Nielsen et al 2013) but may also have a role in compost-related respiratory illness. Endotoxin concentrations of 1.93 EU/m^3 have been recorded in ambient air (Pavilonis et al 2013). An earlier study indicated significant seasonal variability in environmental endotoxin concentrations, with the levels 2 to 3 times higher in spring and summer months than in winter (Carty et al 2003). Oldenburg et al (2007) found endotoxin concentrations above background environmental levels in in the cotton textile industry, and high concentrations of endotoxin have been recorded in the water treatment industry (Smit et al 2005). Millner (2009) noted that exposure to endotoxins, mycotoxins, PM, VOC may occur throughout the composting process, but particularly so during agitation activities such as screening, turning and shredding. In their review of bioaerosol exposures during composting activities, Pearson et al (2015) identified levels of endotoxin and β-glucan during compost agitation activities of 10000 EU/m^3 and 3400 ng/m^3 respectively. Sykes et al (2011) noted a strong correlation between total dust and endotoxin levels using personal sampling methods, indicating that one could act as a surrogate for the other. Concentrations measured using personal sampling methods have generally exceeded static measurements (Sykes et al 2011; Stagg et al 2010). Mycotoxins, which are low-molecular-weight natural products produced as secondary metabolites by filamentous fungi have been linked to various health conditions (Bennet & Klich 2003), but emissions from waste recycling sites have not been widely studied. Mycotoxins of *Aspergillus fumigatus* with tremorgenic properties to induce acute gastrointestinal and neurological disturbances have been found in samples from a German composting facility (Fischer et al 1999). VOCs emitted during the composting process include derivatives of terpenoids, alcohols, organic ketones, esters and acids. Concentrations of up to 40 mg/m^3 have been measured in one study (Persoons et al 2010) and 150 mg/m^3 during aerobic composting processes in a study of 8 facilities in the United States (Eitzer 1995).

1.4. Immunobiology of bioaerosols

1.4.1. Allergic, Toxic and Irritant Effects

Bioaerosol exposure can induce or exacerbate illness in several ways. One way to classify the mechanisms by which these occur is based on the particle's aerodynamic diameter. This measure is calculated as the equivalent diameter of a perfect spherical particle made from a density of 1000kg/m^3 that has the same settling velocity due to gravity as the particle in question. This standardised definition allows the characteristics of particles from different origins, sizes, shapes and geometry to be compared directly. Particles with an aerodynamic diameter of greater than 10 μm are trapped in the nasopharyngeal system, but those measuring less than 10 μm, known as the respirable fraction, may pass deeper and become deposited in the terminal respiratory system. Larger particles are deposited higher up the respiratory tract due to inertial impaction in a size-dependent manner, whereas smaller particles are deposited through diffusion, gravitational sedimentation and electrostatic effects (Thomas 2013). This distinction is important when considering the potential health effects of different bioaerosol components. Accordingly, particles with an aerodynamic diameter larger than 10 μm are less likely to result in lower airways disease, whereas particles of any diameter have the potential to cause upper respiratory tract symptoms. Particle diameter is also a determinant in the aetiology of respiratory conditions related to bioaerosol exposure, such as common extrinsic asthma and extrinsic allergic alveolitis (EAA). Asthmatic reactions are generally provoked by particles ranging from 5-10 μm, whereas EAA is more commonly associated with smaller particles below 5 μm (Horner et al 1995).

An alternative approach is to classify fungi by their potential to cause allergic, toxic and irritant disease. Allergic mechanisms have been associated with rhinosinusitis, allergic asthma and *Aspergillus*-related respiratory illness. In their review article, Denning et al (2006) outline that fungal allergy may derive from several protein families including serine proteases, ribosomal proteins, dehydrogenases and peroxisomal proteins. Allergic responses have traditionally, but not exclusively, associated with IgE (Type I hypersensitivity reaction), but type II, III and IV hypersensitivity mechanisms have been identified as will be described later. Newer evidence also suggests that non-IgE dependent mechanisms may be relevant for some illnesses. Some postulated mechanisms include the involvement of fungal proteases in releasing inflammatory mediators at the site of exposure and direct eosinophilic activation (Reed & Kita 2004). Eosinophils release several substances which are thought to contribute to the pathogenesis of fungal disease to include cytokines, chemokines, arachidonic acid derivatives, eosinophil peroxidase and ribonucleases (Ponikau et al 2006). To complicate matters further, there is evidence to suggest that a single antigen may induce both IgE and non-IgE mediated inflammation. For example, spores of *Trichoderma viridae* have been shown to release histamine from mast cells and basophils in an IgE-dependent fashion at lower concentrations, but IgE-independent at higher concentrations (Larsen et al 1996).

Toxic health effects from fungi are thought to occur from direct cellular injury, particularly from mycotoxins. Mycotoxin groups include aflatoxins, rubratoxins, ochratoxins, fumonisins, and trichothecenes. Aflatoxins were characterised after the death of over 100,000 turkeys from contaminated peanut meal (Blount 1961). The four major aflatoxin groups are B1, B2, G1 and G2 based on their fluorescence under UV light. It is believed that the conversion of aflaxtoxin to its metabolically active 8,9-epoxide form via cytochrome p450 is responsible for toxic health effects. For instance, dietary aflatoxins produced mainly by *Aspergillus flavus* and *Aspergillus parasiticus* in contaminated crops were implicated in causing abdominal pain, vomiting, and human liver disease over 40 years ago (Shank et al 1972). There is also a body of evidence associating dietary aflatoxin exposure and hepatocellular carcinoma (Ross et al 1992). The kidney is the primary target organ for ochratoxins, and members of the ochratoxin family are known to be metabolities of several *Aspergillus* species (Bayman et al 2002). Evidence suggests that ochratoxin exerts its toxic effects through enzymes involved in phenylalanine metabolism, and there is speculation that it is involved in a form of chronic kidney disease known as endemic Balkan neuropathy (Bennett & Klich 2003).

Finally, irritant health effects from fungi may result from exposure to hyphae, spores or substances produced by fungi such as mycotoxin and VOCs (Bush et al 2006). The factors that influence the extent of the irritant response include the concentration and properties of the causative agent; the length of exposure and the sensitivity of the tissue involved. Thus, sensitive tissues such as the mucous membranes of the eyes and nose are more at risk. VOCs produced by moulds include alcohols; esters; carboxylic acids; terpenes; sulphurous and nitrogenous compounds. Hyphae and spores are thought to exert their irritant effects through direct deposition on mucous membranes (Bush et al 2006).

1.4.2. Immunobiology of Compost

This section provides an overview of the *in vivo* immunobiology of bioaerosols in compost. Relevant bioaerosols include whole or fragments of living and dead organisms, as well as substances produced by them or released from them when damaged. I have already described the immunobiology of fungi such as *Aspergillus spp*. and their allergic, toxic and irritant effects. In this section, I shall discuss other relevant bioaerosols.

The *Actinomycetes spp.* are a group of Gram-positive bacilli that are widespread in the environment and grow best in anaerobic conditions (facultative anaerobes). They generally measure between 0.5-1 μm in diameter and grow in filaments. The immunological mechanisms by which they induce illness are thought to involve both Type III (antigen-antibody complex) and Type IV (delayed) hypersensitivity mechanisms. This is based on the delay of symptoms following exposure (Type III), as well as the presence of a cell-mediated response to include lymphocytes, neutrophils and macrophages and the formation of granulomas in the alveolar spaces (Type IV). Wild & Lopez (2001) indicate that the alveolar response is initially neutrophilic, shifting towards a lymphocytic-dominated response later in the disease. Exposure to *Actinomycetes spp*. has been linked to a condition known as extrinsic allergic alveolitis (EAA), also known as hypersensitivity pneumonitis, of which the clinical features will be discussed later.

Endotoxins are associated with both inhalable and respirable dust components, with a predominance in the inhalable fraction (Liebers et al 2006). Important immunological mechanisms in include the attachment to lipopolysaccharide binding protein, CD14 cell surface protein and Toll-Like Receptor 4. It should be noted that Toll-Like Receptor 4 plays a specific role in the immunobiology of endotoxin, whereas Toll-Like Receptors 1, 2 and 6 are associated with lipopeptide, Toll-Like Receptor 3 with doublestranded ribonucleic acid, Toll-Like Receptor 5 with flagellin, and Toll-Like Receptors 7,8 and 9 with other nucleic acids (Sabroe et al 2003). Endotoxin within macrophages and epithelial cells stimulates local production of cytokines (such as TNF-α and IL-6) with a subsequent migration of inflammatory cells into the lung and penetration of cytokines into the blood (Rylander 2002). Aerosolised endotoxin may exist in three forms such as small lipopolysaccharide molecules; lipopolysaccharide associated with other cell wall components; or associated with other aerosolised particles either of biological or inorganic origin (Mattsby-Baltzer et al 1991). Particle sizes in the ambient environment have been measured both in the $PM_{2.5}$ and PM_{10} range (Heinrich et al 2003). Somewhat paradoxically, endotoxin has been linked to both beneficial and adverse health effects depending on when exposure occurs during a person's lifetime. This will be discussed in more detail later.

β-glucans have been linked to the activation of macrophages, neutrophils, monocytes and natural killer cells, thus traversing the innate (non-specific) and adaptive (acquired) immune systems. Their biological activity has been related to their degree of branching and molecular weight, such that higher levels of branching give rise to greater biological activity, with the (1→3) chain essential in the induction of immune responses (Bohn & BeMiller 1995). Evidence also suggests that the cell surface receptor dectin-1 found on macrophages plays an extensive role in phagocytosis, microbial killing and cytokine production, with cytokine production reliant on co-operation between dectin-1 and Toll-Like receptors (Brown et al 2007).

1.5. Possible Adverse Health Effects of Bioaerosol Exposure

1.5.1 Aspergillus and Fungal Disease

This section will discuss the known or suspected adverse health effects of exposure to bioaerosol during compost activities. There are thought to be approximately 200 species of *Aspergillus* but only a few that cause human illness to include *Aspergillus fumigatus, niger and flavus. Aspergillus fumigatus* is of interest given its link to respiratory illness. These include allergic conditions such as allergic bronchopulmonary aspergillosis (ABPA) and allergic aspergillus sinusitis; saprophytic benign disease such as aspergilloma; and invasive disease such as invasive aspergillosis, airway invasive aspergillosis and chronic necrotising pulmonary aspergillosis (Soubani and Chandrasekar 2002). *Aspergillus* colonisation is also associated with severe asthma with fungal sensitisation (SAFS) and hypersensitivity pneumonias (Denning et al 2006).

Aspergillus-related illnesses may involve Type I (immediate hypersensitivity), Type III (antigen-antibody) and Type IV (delayed hypersensitivity; T-cell dependent) responses (Agarwal 2010). Aspergillus-induced asthma is a recognised clinical condition characterised by an immediate Type I IgE mediated hypersensitivity (Shah & Panjabi 2014). It has been established that those sensitised (allergic) to aspergillus experience more severe episodes of asthma. Of all aspergillus-related illness, it is perhaps ABPA that has received most attention in the medical literature, with evidence suggesting that this disease predominantly, but not exclusively, affects those with pre-existing asthma or cystic fibrosis (Agarwal et al 2013). Various genetic factors are thought to be involved in the pathogenesis of the disease including the presence of HLA associations, gene mutations and polymorphisms (TNF-α, IL-4 and IL-15). Type I, Type III antigen-antibody complexes and eosinophil-rich Type IV mechanisms are thought to contribute.

ABPA has been classified into five distinct clinical phases. In the first acute phase, individuals are usually symptomatic presenting with fever, weight loss and wheeze. Recorded total IgE levels may be >1000 IU/ml. Remission with steroid therapy (stage 2) usually occurs within about six weeks associated with a 35-50% fall in total IgE. Between one-quarter to one-half of individuals experience an exacerbation of the disease (stage 3), and in stage 4 patients become dependent on glucocorticoids. Stage 5 has been classified as end-stage fibrosis with pulmonary dysfunction such as hypercapnic respiratory failure with or without cor pulmonale (Agarwal 2009).

The diagnosis of ABPA has traditionally been made using the Patterson criteria. Modifications to these criteria take account of the relative contribution of each factor in diagnosing ABPA, such that a greater emphasis is placed on elevated IgE levels for example (Agarwal 2010). A set of modified criteria for ABPA diagnosis have been proposed (Dhooria & Agarwal 2014) which include:

• Elevated serum IgE levels against *A. fumigatus* (>0.35 kUA/l) or immediate cutaneous hypersensitivity to *A. fumigatus* antigen (positive Type I *Aspergillus* skin test)
• Raised serum total IgE levels (>1000 IU/ml)
Other criteria (at least two of three)
• Presence of precipitating (or IgG) antibodies against *A. fumigatus* in serum
• Thoracic imaging findings consistent with allergic bronchopulmonary aspergillosis
• Peripheral blood eosinophil count >500 cells/μl

Table 2: ABPA diagnostic criteria

Patterson criteria for diagnosis of ABPA include a raised serum total IgE greater than 1000 IU/ml with a positive skin prick test or serum IgE to Aspergillus fumigatus

The requirement to consider minor criteria in the diagnosis of ABPA has been removed. Studies have also indicated that high-resolution computed tomography scanning can differentiate between ABPA with central bronchiectasis and serologically positive ABPA. It has been suggested that the clinical value of this distinction is that individuals with ABPA-CB can be identified early to offset repetitive infections that lead to worsening central bronchiectasis (Kaur & Sudan 2014).

Other clinical syndromes related to *Aspergillus* exposure have been noted. Chronic simple aspergilloma follows a relatively benign course, whereas more aggressive forms of chronic disease include necrotising pulmonary aspergillosis which appears to be associated with the presence of underlying lung disease such as chronic obstructive pulmonary disease (COPD), tuberculosis or sarcoidosis. SAFS is characterised by severe (poorly controlled) asthma; immunological sensitisation to an array of fungi which may include *Aspergillus spp*, a normal *Aspergillus*-IgG level and an absence of the radiographic features of ABPA (Patterson & Strek 2014).

The role of *Alternaria alternata* and *Cladosporium herbarum* in causing human illness is also documented. Both fungi may be found in compost, In immunocompromised individuals, these organisms can induce a condition like ABPA, in this case known as an allergic pulmonary mycosis. More commonly however, exposure to these fungi has been linked to episodes of rhinitis, rhino-conjunctivitis and exacerbations of asthma (D'Amato et al 1997). In a study conducted across 12 European regions, it has been shown that the prevalence of sensitisation to these moulds rise with increasing asthma severity, but not with sensitisation to pollen or cats (Zureik et al 2002).

1.5.2. Illness associated with other bioaerosol components

As described earlier, exposure to *Actinomycetes spp.*, their spores or hyphae has been linked to extrinsic allergic alveolitis (EAA), also known as hypersensitivity pneumonitis. EAA has been observed in the farming, sugar, mushroom and woodwork industries as well as in workers exposed to metalworking fluid (Barber et al 2012). With respect to compost, both *Aspergillus fumigatus* and *Thermophilic actinomycetes* have been implicated in cases of EAA (Wery 2014). EAA subtypes include acute, sub-chronic and chronic forms. The acute form presents within 4-8 hours of exposure to the causative antigen. Symptoms, which usually resolve within 48 hours, include cough, wheeze and shortness of breath accompanied by fever, sweating and myalgia. In the subacute form, individuals experience a gradual onset of these symptoms with a progressive course, which may be superimposed by acute attacks. Anorexia, weight loss and fatigue may occur, and finger clubbing may be present (Hirschmann et al 2009). Finally, the chronic form of the condition is associated with emphysema, fibrosis or both which may develop in the absence of acute attacks (Ismail et al 2006). The diagnosis of EAA is made from a combination of findings from the clinical history, examination and investigations including serology, radiography, lung biopsy and bronchoalveolar lavage. The latter characteristically reveals a lymphocyte content of more than 30% and may demonstrate a ratio of CD4-to-CD8 cells of less than 1 (normal = 1.8). It has been reported this can help distinguish EAA from sarcoidosis where this ratio is often elevated above normal values (Hirschmann et al 2009).

The health effects of endotoxin vary according to the point of time at which they are exposed. Epidemiological studies have demonstrated that endotoxin exposure has a protective effect for developing atopic asthma during childhood but has been linked to exacerbations of non-atopic asthma and other adverse respiratory effects in adulthood (Remes et al 2003). At lower concentrations, they have been linked to the development of mucous membrane irritation, upper airways inflammation and bronchoconstriction (Liebers et al 2006). At higher levels, such as those encountered by agricultural seed handlers where mean endotoxin concentrations of 1800 EU/m^3 have been measured, there are case reports of organic dust toxic syndrome (ODTS) (Smit et al 2006). ODTS presents similarly to EAA with respiratory symptoms to include cough, wheeze, shortness of breath and systemic symptoms such as malaise, fever and arthralgia. Once again, recovery usually occurs within 24 hours but Luc et al (2005) suggest that with repeated exposure, tolerance may develop to at least the systemic components. In contrast to EAA however, there are no long-term sequelae of ODTS. EAA may also be associated with the presence of IgG sensitisation to the offending antigen, which may be a method to distinguish the two conditions. Donham et al (2000) demonstrated a dose-response relationship between increasing endotoxin concentrations and acute decreases in lung function as measured by FEV_1 in poultry farmers. It has also been suggested that the prevalence of atopic asthma seem to be lower in those exposed to endotoxin, whereas the reverse applies for non-atopic asthma (Radon 2006).

Airborne exposure to β –glucans has been linked to respiratory tract irritation (Douwes 2005). There have been few studies examining health effects associated with glucan exposure from compost. Nonetheless, elevated levels of β –glucan have been identified during composting agitation activities (Sykes et al 2011). Heldal et al (2003) suggest that endotoxin plays a greater role in stimulating IL-8 production than β –glucan. This led the authors to suggest that endotoxins may play a more prominent role in inducing irritant respiratory symptoms than glucan exposure. Nonetheless in office environments, β –glucan has been shown to independently potentiate the effects of upper airways inflammation associated with exposure to dust (Bonlokke et al 2006).

The relationship between bioaerosol components, the mechanisms in which they induce ill-health and the resulting illnesses is complex. For clarity, a summary of this information is presented in the table below:

Compost Component	**Mechanisms**	**Known or Suspected (S) Illness**
Fungi	Allergic (Type I, III, IV) Toxic Irritant	Rhinoconjunctivitis (S) Severe Asthma Extrinsic Allergic Alveolitis Fungal Sinusitis Invasive airways disease Allergic bronchopulmonary mycoses (e.g. ABPA)
Actinomycetes spp.	Allergic (Type III, IV)	Extrinsic Allergic Alveolitis
Endotoxin	Neutrophil-dominated inflammation	Airway irritation Bronchoconstriction Decreased Lung Function ODTS
β –glucans	Immunomodulation (phagocytes, macrophages, monocytes, dendritic cells)	Airway Irritation
Fungal by-products such as mycotoxin and VOCs	Toxic Irritant	Mucous Membrane Irritation Respiratory Tract Irritation

Table 3: Illnesses associated with bioaerosol components in compost

The table above illustrates the main respiratory illnesses associated with different bioaerosol components (final column) along with the main mechanisms by which they are induced (middle column). Fungi are responsible for allergic illness with their by-products producing toxic and irritant effects. Gram-negative bacteria produce Type III/IV allergic responses, whereas endotoxin exposure is characterised by a neutrophil activation.

1.6. Respiratory illness and lung function in compost workers

The main studies that have examined symptoms and/or the relationship between exposure and symptoms in compost workers are discussed here. Relevant presenting symptoms include mucous membrane irritation (MMI) of the upper airways resulting in rhino-conjunctivitis, as well as bronchial responses resulting in cough, wheeze and shortness of breath.

Data suggest that there are higher prevalences of ocular, nasal, skin and gastro-intestinal symptoms in waste industry workers than the general population (Sigsgaard et al 1994; Bunger et al 2000; Herr et al 2003; Wouters et al 2002; Bunger et al 2007; Hambach et al 2012). Prolonged exposure to bioaerosol has been linked to the development or exacerbation of obstructive respiratory conditions such as asthma and chronic bronchitis (Zuskin et al 1994; Matheson et al 2005), as well as progressive lung function decline (Douwes 2005). Whilst a cross-sectional study found no difference in lung function according to the exposure status of compost workers (Muller et al 2006); a longitudinal study conducted over a 5-year period in Germany identified a higher risk of chronic bronchitis and greater rate of lung function decline in compost workers as compared to general population controls (Van Kampen et al 2012). Studies have also identified a greater cross-shift lung function decline, as measured by forced vital capacity (FVC), in compost workers compared to controls (Sigsgaard et al 1994; Bunger et al 2000; Van Kampen et al 2012). More recently a statistical association between upper and lower airways irritation in former compost workers has been identified when excluding allergic asthmatics from analysis, leading the authors to suggest that the presence of chronic bronchitis in these workers may reflect a chronic irritative process triggered by previous bioaerosol exposure (Hoffmeyer et al 2014).

There are a few case reports of EAA in compost workers (Millner 1995; Brown et al 1995; Bunger et al 2007). There are also case reports of compost workers developing the condition that have underlying medical vulnerabilities such as pre-existing asthma and sarcoidosis (Allmers 2000; Poole & Wong 2013). Studies have identified higher complaints of gastrointestinal (Ivens et al 1997; Hambach et al 2012) and skin symptoms in compost workers than the general population (Bunger et al 2000). The mechanisms by which these symptoms occur are unclear but a relationship with endotoxin has been hypothesised for nausea, and endotoxin and fungi for diarrhoea (Ivens et al 1997).

Several community health studies of individuals living or working near composting sites have been conducted, many of which mirror findings in occupational settings. One cross-sectional German study identified significantly elevated odds ratios of 3.59, 6,59 and 3.18 of having symptoms of bronchitis, being woken up by coughing, and coughing during the day for residents living within 500 meters of a composting facility than those residing further away (Herr et al 2003). Similar findings were reported in a recent Finnish study (Aatamila et al 2011). Higher prevalences of eye, nose and throat irritation; gastrointestinal symptoms such as nausea and vomiting; and flu-like symptoms were also reported by residents living close to compost sites in both studies, but such associations have not been consistently found (Cobb et al 1995).

1.7. Sensitisation

1.7.1. Identification and Relevance

Sensitisation refers to the capability of an antigen to induce allergic responses and is the result of a complex interplay between genetic susceptibility, environmental factors and host factors. Host factors include the physical, chemical and immunological barriers provided by epithelium. In the respiratory system, this physical barrier is composed of receptors, transporters and tight junctions within the airways which hydrate the mucus layer to provide optimal conditions for cilia to function. The chemical barrier contains mucins, antioxidants and defence molecules which trap and inactivate particles and are subsequently cleared by the muco-ciliary escalator. The immunological barrier is provided by a variety of cells including dendritic, mast, eosinophil and T-cells encompassing both innate and adaptive responses. Allergens however can alter these barriers to induce disease, for which some mechanisms were discussed earlier.

The *in vivo* skin prick test (SPT) is widely used to identify sensitisation. This method uses skin sensitivity as a proxy for IgE-mediated sensitisation found within target organs such as the eyes, nose and lungs in the human host. When an antigen is introduced on to the skin, specific IgE bound to the surface of mast cells are cross-linked and degranulate, leading to the release of histamine and other inflammatory mediators (Heinzerling et al 2013). A positive reaction may present on the skin as a wheal, flare, or a combination of the two. Until recently, there had been concerns regarding the lack of standardisation of SPT practices in European centres. In response, the Global Asthma and Allergy European Network conducted a study to analyse patterns of sensitisation to common aero-allergens across Europe, for which a standardised pan-European skin prick testing panel was developed (Heinzerling et al 2009).

The main reported advantage of the SPT compared to *in vitro* specific IgE antibody measurement in blood is that the result can be interpreted more quickly, within 15 to 20 minutes of administration. The *in vitro* method however remains an important tool not least because the SPT may be inappropriate in individuals with widespread skin disease such as eczema, or inaccurate in the presence of medications that interfere with the test such as antihistamines. Nonetheless, concerns have been raised about the limited sensitivity and specificity of *in vitro* tests, and the clinical relevance of low levels of specific IgE antibodies in the presence of high total IgE serum antibodies (Hill et al 2004; Chung et al 2010). Concordance between the two tests have ranged from 85%-95% depending on the allergen tested, and the SPT has been shown in one study to be superior to in vitro methods in positively predicting clinical allergy for respiratory diseases (Heinzerling et al 2013).

There is evidence from epidemiological studies that individuals sensitised to a single allergen (monosensitised) differ in their immune response to those sensitised to multiple allergens (polysensitised) (Migueres et al 2014). A large cross-sectional study of 2415 patients identified no differences in the prevalence of allergic rhinitis between these groups but that polysensitised individuals may experience more significant symptoms (Ciprandi & Cirillo 2011).

1.7.2. Sensitisation in Compost Workers

There is relatively little work examining the sensitisation status of compost workers using standardised methods such as the SPT or blood results. A 1989 Danish study examined the serological status of 9 general waste workers (as opposed to specifically compost workers) complaining of respiratory health problems, of which two had positive SPTs (Malmros et al 1992). A subsequent paper in 1994 on a group of 72 Danish refuse workers and 119 controls indicated higher total IgE, IgG and eosinophils in the former group. Of note however, only 8 compost workers were involved, and the authors noted that significant differences in IgE concentrations between groups were due to a single outlier result from a compost worker with allergic asthma and rhinitis. The methods section of the study also refers to having conducted skin prick testing on participants, but no results are reported.

A later study demonstrated an increase in serum IgG concentrations to moulds and bacteria in compost workers, specifically *Aspergillus fumigatus, Streptomyces rectivirgula and Streptomyces thermovulgaris* (Bunger et al 2000). The authors also stated that these elevated IgG concentrations correlated well with diagnosed cases of work-related disease as well as duration of employment after controlling for confounding variables. A more recent study conducted by Van Kampen et al (2012) however presented contrasting findings. The total IgE concentrations and specific IgE concentrations to mould mixture MX1 (*A. fumigatus, C. herbarum, P. notatum and A. alternata*) as well as environmental mixture SX1 (house dust mite, cat, dog, timothy grass, rye grass, birch and mugwort) in 190 compost workers and 38 non-exposed controls were analysed. Specific IgG concentrations to *A. fumigatus, Penicillium spp, S. rectivirgula and T. vulgaris* were also measured. The authors reported no significant differences between compost workers and controls for any of these measurements but noted that high specific IgE concentrations (>0.35 kU/L) were only found in the exposed group.

1.8. Managing Bioaerosol Exposure

1.8.1. Legislation

Current bioaerosol legislation is based upon existing evidence about the distribution of particles across outdoor compost sites. An HSE study suggested that concentrations of fungi such as *Aspergillus fumigatus* and bacteria such as *Actinomycetes spp.* fell to background levels at 50 metres upwind and 250 metres downwind from the source of generation (Stagg et al 2010). This work informed the development of 'risk zones' which quantifies likely bioaerosol exposures (total bacteria, total fungi, *Aspergillus fumigatus and Thermophilic actinomycetes)* according to distance from the source. Zones are coded as red (immediately proximity); orange (within 50 metres); yellow (50-100 metres) and green (100-250 metres). The work conducted by the HSE has also informed the recommendations made by the Environment Agency in England and Wales for the acceptable upper limits of bioaerosol concentration at 250 metres downwind from compost sites. These are total bacteria at 1000 cfu/m^3; *Aspergillus fumigatus* at 500 cfu/m^3 and Gram-negative bacteria at 300 cfu/m^3 (Environment Agency 2010).

Currently, there are no legal occupational exposure limits for bioaerosol exposure in the UK. UK Workplace Exposure Limits (WELs) for most inhalable and respirable inorganic dusts have been set at 10 and 4 mg/m^3 respectively, but it is not certain whether these are appropriate for bioaerosols generated from compost. A UK study conducted across nine recycling facilities showed an increase in symptoms of nasal irritation and sneezing at inhalable dust concentrations greater than 5mg/m^3 but not with lower airways complaints such as cough or shortness of breath (Gladding et al 2003). With respect to endotoxin, a 'health-based' occupational exposure limit of 90 EU /m^3 or 5 ng/m^3 over an eight-hour period has been recommended by the Dutch Expert Committee on Occupational Safety (DECOS 2010). This value was derived from a five-year study of animal feed workers exposed to endotoxin from cotton, suggesting that a forty-year exposure would on average lead to no more than a 120-millilitre decrement in lung function, as measured by forced expiratory volume over 1 second (FEV_1). In Scandinavia, Rylander (1999) proposed limits of 5 mg/m^3 for total dust; 10^7 cfu/m^3 for fungi and 10^5 cfu/m^3 for Gram negative bacteria. A limit of 10^6 cfu/m^3 has been proposed for non-pathogenic, non-mycotoxin producing fungal spores based on their ability to induce illnesses such as ODTS and subclinical inflammation in the respiratory tract (Eduard et al 2012). Duquenne et al (2013) noted however that there is considerable variability between studies and across industries as to the endotoxin concentrations at which symptoms start to appear. Bioaerosol research is yet to identify workplace OELs for other components.

1.8.2. Controls for Bioaerosol Exposure

There are numerous regulations covering the control of workers' exposure to substances that are known or suspected to cause harm to health. UK employers are required to control such occupational exposures under the Control of Substances Hazardous to Health Regulations 2002. These regulations cover occupational exposure to biological agents and chemicals which may be absorbed through skin, mucous membrane such as the eyes, ingested or inhaled. Chemical exposure may occur in solid form such as dust or fume; liquid such as vapours and mist, or gases.

The HSE has outlined a hierarchy of measures to control exposure to substances which are hazardous to health. The first recommended steps are to consider whether the hazard can be eliminated or substituted with an alternative process. If this is not possible, or control is inadequate using these measures, the next stage is to determine whether there are suitable engineering or administrative controls that can be used to reduce exposure. Engineering controls may include complete or partial enclosure of a process. Other methods include the use of general or local exhaust ventilation and extraction. Administrative controls may include exclusion of the worker from the process or job rotation. The final control methods to consider include the use of standard operating protocols; information, instruction and training for workers, and the use of personal protective equipment appropriate for the tasks performed such as masks, overalls and gloves.

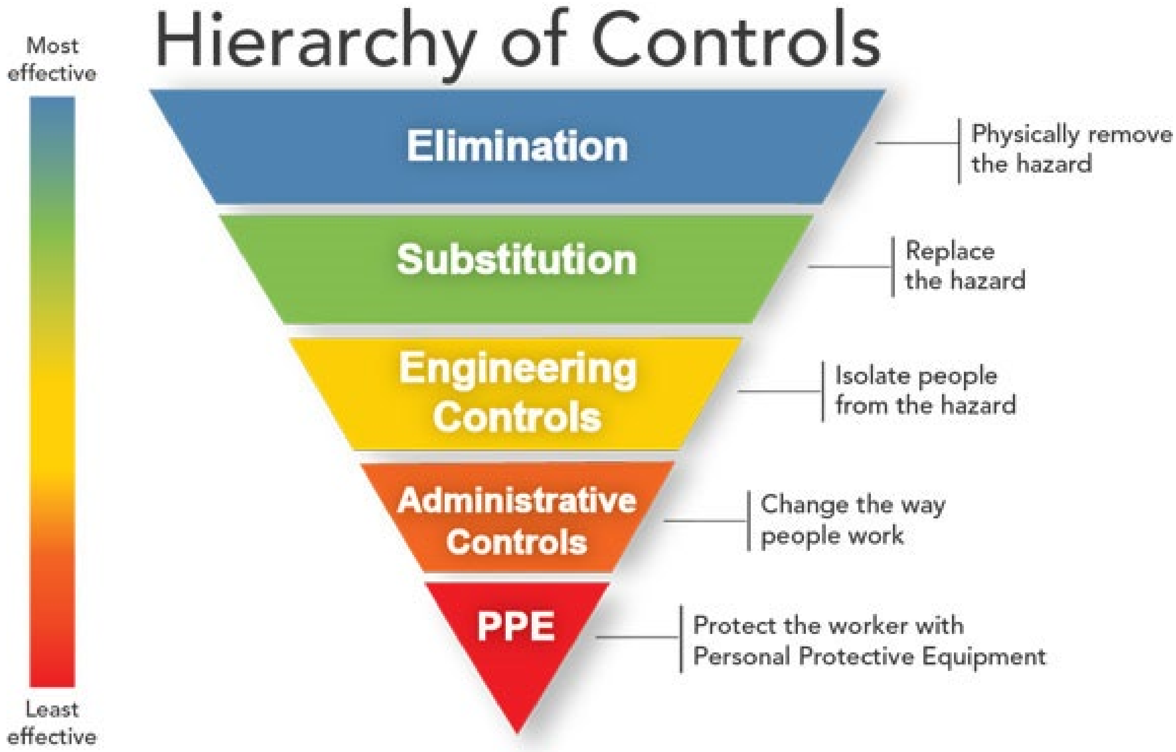


Figure 7: Hierarchy of Controls

The figure demonstrates the hierarchy of controls measures to prevent work-related illness or injury proposed by the HSE, beginning with elimination of the hazard or substitution with a less hazardous process; engineering controls to reduce exposure, administrative approaches such as work rotation or exclusion, and finally the provision of personal protective equipment.

There are relatively few studies that have examined the effectiveness of controls to reduce or eliminate bioaerosol exposure in compost workers. One study examined the effectiveness of the protection afforded by vehicles and filters at open windrow and indoor sites, which included five front-end loaders, two agricultural tractors and one mobile mixer. Vehicles with pressurised systems utilising high efficiency particulate air (HEPA) filters were shown to provide near 100% protection against fungi, bacteria and endotoxin. Those employing pleated paper systems however were less effective against all three forms of bioaerosol, but with better protection against bacteria than fungi for which the reasons were unclear. Suggested contributors included penetration through the only moderately efficient filters, the absence of pressurisation, leakage in the filter-sealing system, and re-suspension of particles accumulating in dirty cabs

(Schlosser et al 2012). Other authors have commented on the importance of maintaining cabs and filters in adequate conditions, such as replacement of parts and cleaning (Stagg et al 2010; Sykes et al 2011) but few studies have examined this in detail. This may also be of relevance in those workers using respiratory protective equipment (RPE), and those working in cabs may not necessarily work with their doors and windows closed. Hagemeyer et al (2013) noted however that there has been little work examining workers' compliance with RPE or the factors that influence it.

1.8.3. Health Surveillance for Compost Workers

Health surveillance is the practice of detecting cases of ill-health at an early stage to protect the health of workers; recognising workers or groups of workers at further risk of developing occupational illness; identifying new hazards to health; reviewing the effectiveness of risk assessments and control measures; and complying with legislation. The Control of Substances Hazardous to Health Regulations 2002 specify that health surveillance is required where employees are exposed to a substance which is known or suspected to adversely affect human health; there is a reasonable likelihood of a specific disease or adverse health effect occurring under the conditions of work; and it is possible to detect the disease or adverse health effect (HSE 2003). The HSE have produced a 'health surveillance cycle' to guide organisations in developing a surveillance program. This includes determining the need for surveillance and the type of surveillance required; ensuring delivery by appropriately qualified individuals and having appropriate equipment to carry out the data collection; developing a system for capturing and analysing data and establishing mechanisms by which to evaluate the effectiveness of the program. Workers exposed to bioaerosols from compost would fulfil these criteria.

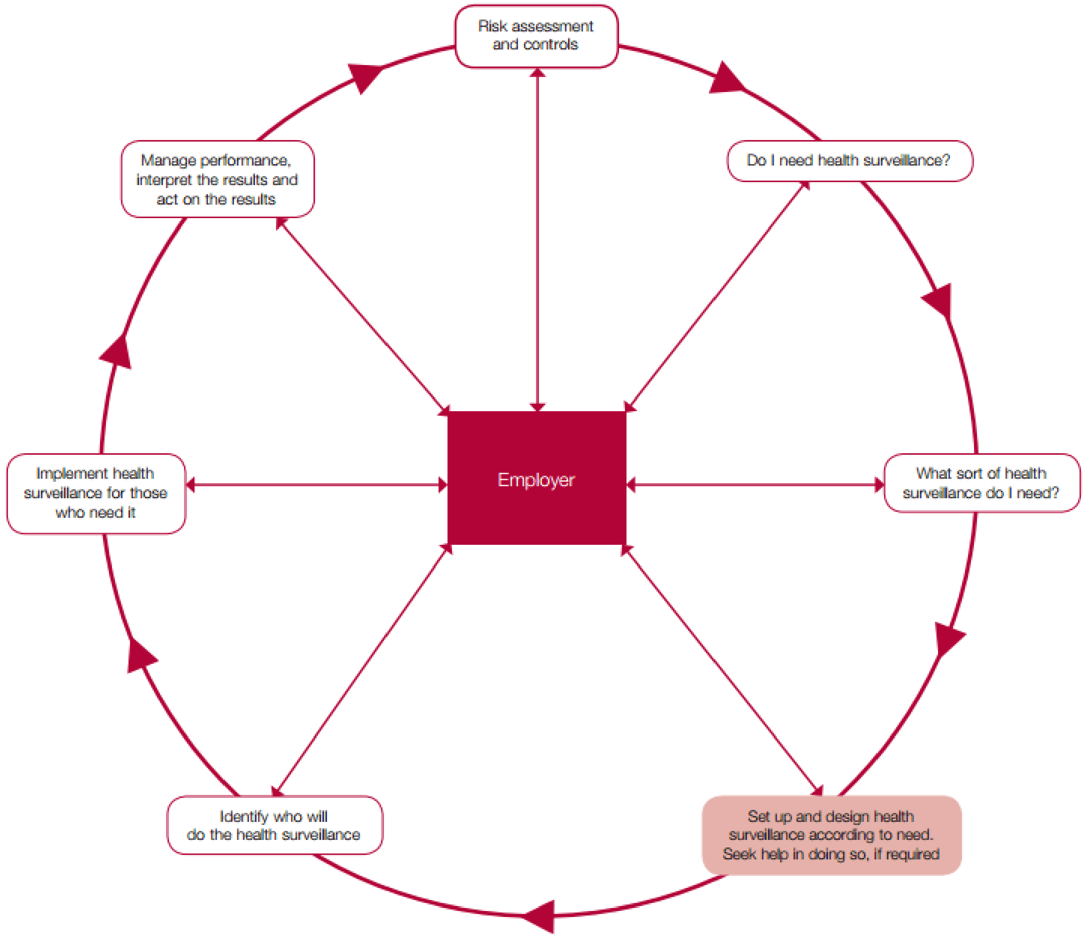


Figure 8: The Health Surveillance Cycle, HSE

Figure shows the health surveillance cycle for workers who are known to or suspected to be at risk of developing occupational disease, as recommended by the HSE. Important steps include identifying the method of health surveillance needed and how often it should occur, who is responsible for delivery and managing the process, and establishing robust evaluation methods.

Health surveillance methods can be classified as 'non-technical' or 'technical'. Non-technical approaches may include questionnaires assessing symptoms of ill-health or physical examination such as of the skin for contact dermatitis. Technical methods could include the use of spirometry to measure lung function, or audiometry to identify cases of sensorineural hearing loss secondary to occupational noise exposure. Other adjuncts may include the use of biological monitoring to directly measure exposure to hazardous substances or their metabolites in blood, urine or breath.

The current health surveillance practices of occupational health providers for workers in the UK composting industry are not known, and there are no published studies on this topic. Furthermore, the optimal process for conducting health surveillance in this sector has not been established but may include detecting the health symptoms at an early stage through a health questionnaire; exclusion of vulnerable workers such as those with pre-existing lung disease or who are immunosuppressed, and the use of relevant skin, blood and respiratory function tests.

1.9. Summary

There has been a growth of research into the potential health risks of working with green waste in the last 30 years. Nonetheless, this chapter has identified a preponderance towards bioaerosol exposure studies, with less emphasis on clinical outcomes such as sensitisation and symptoms. There is little work assessing the relationships between exposure, sensitisation and health. The dearth of case-reports of ill-health in the industry may have a few explanations. The first is that cases are not identified or misdiagnosed as other illnesses. Another is that existing control measures are sufficient to prevent cases of occupational disease. A third is that cases may be identified but under-reported to work surveillance schemes. Further work in this area may include:

- Understanding the prevalence of work-related symptoms and occupational illness in the industrial composting workforce. No large-scale studies have been published in the UK thus far.
- Examining the epidemiology of sensitisation to bioaerosols in compost workers.
- Identifying suitable health surveillance processes for compost workers
- Establishing the utility of skin-prick tests and blood tests in determining the prevalence of sensitisation to allergens found in bioaerosols from compost.
- Assessing the relationship between sensitisation and symptoms. Longitudinal studies could establish whether those who are sensitised are more likely to develop illness.
- Longitudinal follow up studies of the lung function of workers exposed to bioaerosols from compost to provide further information regarding a potential increased risk of lung disease such as chronic bronchitis (Van Kampen et al 2012).
- Understanding variations in exposure according to environmental conditions and setting, such as indoor and outdoor sites which could inform the management of composting processes.
- Setting an occupational exposure limit for bioaerosol exposure.

The importance of understanding the epidemiology of sensitisation, symptoms and established clinical illness in compost workers is clear. Identifying sensitised workers and those with symptoms at an early stage would inform their occupational management, particularly those with underlying vulnerabilities which may predispose them to illness.

Little is known about existing occupational health surveillance in the industry. The relevance of skin prick and blood tests for sensitisation has not been established, nor has the use of spirometry for lung function assessment. It is also unclear as to what questions are currently asked of workers to identify symptoms which may be suggestive of occupational illness, or whether these are sensitive enough to identify subtle cases of disease such as EAA, ODTS and ABPA. There are several studies in the literature which refer to the use of health questionnaires, but none were explicit as to what questions were asked. Establishing occupational exposure limits for bioaerosol emissions is challenging not least because of the overlap in illness caused by different bioaerosol components. There is likely to be variation between individuals as to the concentration of bioaerosol at which these symptoms occur. Variations in bioaerosol exposures according to climate, site activity and setting (indoor vs. outdoor) would also need to be understood. These variations may be considered as 'uncertainty factors' in deriving occupational exposure limits.

The next chapter shall describe the findings from a systematic review of occupational illness from the composting sector. Following this, the process used to recruit composting companies and participants into the study shall be covered, including relevant ethical and governance issues. The following chapter will describe results from empirical studies of bioaerosol emissions from two sampled sites, the burden of occupational illness amongst workers and an evaluation of the psychometric properties of the questionnaire.

Chapter 2: Systematic Review of Occupational Illness in the Composting (Green Waste) Recycling Sector

2.1. Introduction

The waste recycling sector is worth £12 billion per year to the UK economy. It employs over 200,000 people and is growing at 3-4% per year. The main drivers for this include international, European Union (EU) and national legislation to reduce waste production and generation such as an EU Directive to recycle 50% of all landfill waste by 2020. Other drivers include promoting resource sustainability and redressing emissions from landfill incineration contributing to climate change.

Despite the benefits to society in promoting recycling, there are known and suspected health hazards for the workers involved, and potentially those living nearby. The prevalence of fatal and non-fatal injury for workers in the sector is much higher than the industrial average with potential health hazards including heavy manual handling; bioaerosol exposure from garden, domestic or food (biomass) waste, as well as heavy metal exposure including lead and mercury from the recycling of batteries, fluorescent lights and electrical equipment (HSE 2015). Concern has been expressed by the Health & Safety Executive (HSE) in the UK about inadequate risk assessments, inadequate workplace controls, insufficient washing facilities and a lack of appropriate risk-based health surveillance as part of a quality management process at inspected workplaces in the UK (Stagg et al 2013). Some hazards, such as musculoskeletal injury through manual handling activities are known and are best managed by limiting loads or engineering controls such as the automated lifting of wheelie bins to tip waste into the back of lorries. Other hazards may be suspected, such as exposure to bioaerosols from biomass-fired power plants or on industrial composting sites where concentrations up to 1000 times greater than in ambient air have been measured (Swan et al 2003). Bioaerosols may comprise living or dead organisms; spores; substances released from cell walls when they rupture such as endotoxins and beta-glucans; or substances produced by organisms such as exotoxins and mycotoxins. These may cause toxic, irritant or allergic health effects. How exposure should be controlled and to what degree is uncertain. Whilst exposure limits of 10 mg/m^3 8-hour time weighted average exist for inorganic dust, there are no limits for the constituents of bioaerosols mainly because of the difficulty of establishing a dose-response effect and safe levels of exposure, although a Dutch Expert Committee has recommended health-based limits of 10^4cfu/m^3 for bacteria in air and 90 EU/m^3 (5 ng/m^3) for endotoxins (Swan et al 2003). Furthermore, how health surveillance should be done for these exposures is unknown but should include the early detection of symptoms and signs associated with acute and chronic illnesses. Relevant respiratory symptoms include rhino-conjunctivitis, cough, wheeze, chest tightness and shortness of breath. Systemic symptoms include fever, myalgia, fatigue and weight loss. One or more of these symptoms may be associated with occupational asthma, chronic bronchitis and chronic obstructive pulmonary disease (COPD), as well as rarer conditions such as extrinsic allergic alveolitis, organic dust toxic syndrome and allergic bronchopulmonary aspergillosis. I undertook a systematic review of the literature to identify known hazards, biological effects and occupational illnesses for workers in the composting sector which I hope shall be of use to occupational health practitioners.

2.2. Methods

The literature search was conducted with the support of Miss Victoria Wollerton, a professional librarian at the Health and Safety Laboratory. The following databases were examined: Web of Science, Medline, Embase, Health and Safety Science Abstracts, Osh Update, e-library and Google Scholar. Original research papers and case reports published in peer-reviewed journals between 1995 and 2015 on composting were identified. The timeframe was chosen as the vast majority of studies of bioaerosol emissions and occupational illness in the composting sector have been conducted since 1995. Additionally, methods used to assess bioaerosol emissions have remained consistent during this period. We used predetermined terms to link the categories of population such as worker, with the environment such as waste; health such as alveolitis and exposure such as mycotoxin. The search strategy for composting and municipal waste is shown in the table below. The terms in the four columns below were combined using "AND".

Population (e.g. worker terms)	Environment (e.g. specific industry sector)	Health effect (e.g. illness or disease)	Type of exposure
worker* or collector* or occupation* or employ* or staff or operative* or job or jobs or recycler* or industry or industries or facility or facilities or labourer*	**Composting / biomass / green waste**		
	compost* or ((garden or organic or food or vegetation or biodegradable or green) near/3 (waste* or material*)) or biomass or windrow or "anaerobic digestion" or (anaerobic near/1 closed) or "in vessel compost*"	aspergillosis or "allergic alveolitis" or asthma* or lung or lungs or respirat* or bronchi* or broncho* or pneumonitis or (dust near/2 toxic) or "ABPA" or rhinoconjunctivitis or "rhino conjunctivitis" or rhinitis or conjunctivitis or gastrointestinal or "gastro intestinal" or "manual handling" or allerg* or sensitis* or sensitiz* or musculoskeletal or skin or mycotoxicosis or nasal or nose or eyes or derma* or infection* or airway* or toxic* or chest or pulmonary or pneumoconiosis or muscle or muscles or limb or limbs or hypersensitivit* or ocular or COPD or cancer*	expos* or breath* or inhal* or spores or mold or mould or fungi or fungus or endotoxin* or mycotoxin* or glycan* or bioaerosol* or bacteria or methane or "hydrogen sulphide" or "micro-organism*" or microorganism* or dust or dusts

Table 4: Search Strategy for Systematic Review

The table displays the four-stage search strategy used to identify relevant articles to include in this systematic review of occupational illness in the waste and recycling sector. The first theme relates a population heading, followed by environment, health effect and exposure. Several variations of terms were applied under each sub-heading to improve the scope of the review.

The titles and abstracts were reviewed separately by Dr. Subhashis Basu and Dr. Jon Poole, both occupational physicians. Papers relevant to exposure, biological effect or occupational illness and in English were selected. Papers were grouped into the following sectors: composting, municipal or domestic solid waste and toxic waste; metal, batteries, cables and wires; glass and fluorescent lights; landfill, textiles and wood; medical waste, paper and nappies; waste electronic electrical equipment

(WEEE). As most sectors generated only a few papers, a narrative review was conducted for them, as was presented in the first chapter of this thesis.

The findings from the systematic review were reported using the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) flowchart. The Scottish Intercollegiate Guidelines Network (SIGN) grading system was used for systematic and narrative literature reviews and for case reports. This system uses the following scale:

1++	High quality meta-analyses, systematic reviews of RCTs, or RCTs with a very low risk of bias
1+	Well-conducted meta-analyses, systematic reviews, or RCTs with a low risk of bias
1-	Meta-analyses, systematic reviews, or RCTs with a high risk of bias
2++	High quality systematic reviews of case control or cohort or studies High quality case control or cohort studies with a very low risk of confounding or bias and a high probability that the relationship is causal
2+	Well-conducted case control or cohort studies with a low risk of confounding or bias and a moderate probability that the relationship is causal
2-	Case control or cohort studies with a high risk of confounding or bias and a significant risk that the relationship is not causal
3	Non-analytic studies, e.g. case reports, case series
4	Expert opinion

A modified version of the Newcastle-Ottawa Scale was used for observational studies (Wells et al 2011). Papers were rated independently by each author and any differences corrected through discussion.

Selection Bias Max 5 points	1. Was the sample representative of the population? 2. Was more than one site studied? 3. Was a power calculation undertaken?

	4. Did the authors use standardised measurement tools to assess exposures? 5. Did the authors use standardised measurement tools to assess outcomes?
Comparability Max 3 points	1. Have confounding factors been assessed? (Max 2 pts) 2. Did the study employ an appropriate control group?
Outcome Max 2 points	1. Were statistical tests appropriate? 2. Were conclusions justified?

Table 5: Modified Newcastle-Ottawa Grading Scale

The Newcastle-Ottawa Grading Scale to assess the quality of cross-sectional studies was modified for this review to enable standardised grading across papers. Five points pertain to the absence of features of selection bias; three points for assessment of confounding and use of a control group, with two for aspects of the outcome.

The Health and Safety Executive's Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR) database was also scrutinised for cases of work-related illness reported from the waste and recycling sector between 2005 and 2015. The Health and Occupational Research (THOR) network database of work-related illnesses held at the Centre for Occupational and Environmental Health, University of Manchester was also searched for reported cases. THOR includes the Occupational Physician Reporting Activity (OPRA 1996 - 2015), Surveillance of Work-Related and Occupational Respiratory Disease (SWORD 1989-2015), Occupational Skin Surveillance Scheme (EPIDERM 1993-2015), The Health and Occupational Research network in General Practice (THOR-GP 2006-2015), Musculoskeletal Occupational Surveillance Scheme (MOSS 1999-2009), Surveillance of Stress and Mental Illness (SOSMI 1999-2009), Surveillance of Infectious Diseases at Work (SIDAW 1996-2015) and Occupational Surveillance Scheme for Audiological physicians (OSSA 1996-2015).

2.3. Results

Composting, Municipal and Domestic Solid Waste

Two hundred and seventy-three abstracts were reviewed which included 34 reviews, 184 observational studies and 10 case reports. The main reported hazards were heavy manual handling, inorganic dust, bioaerosols, volatile organic compounds and incinerator emissions to include polycyclic aromatic hydrocarbons, heavy metals, dioxins and furans. 34 papers were included in the final review, of which 30 related to bioaerosol exposure, and 4 to other hazards.

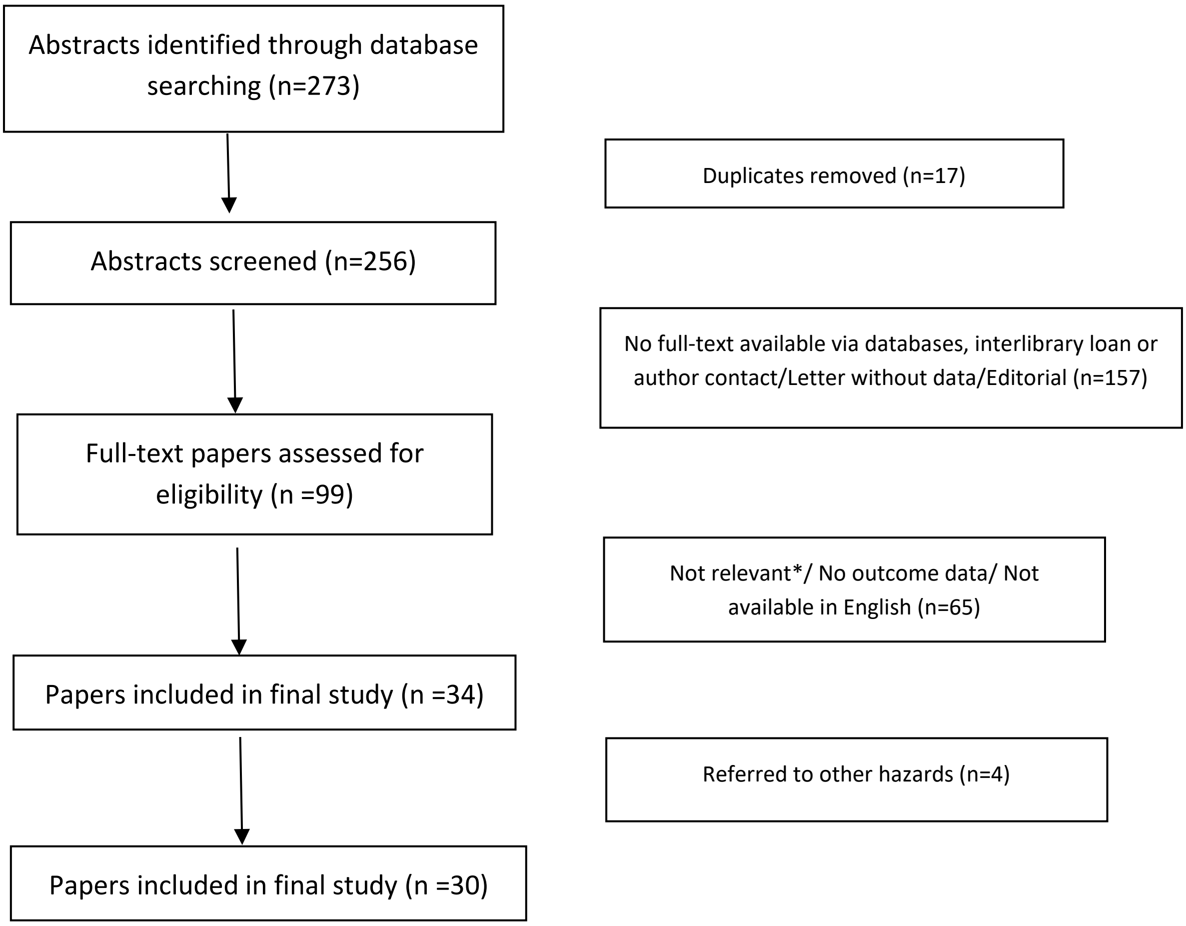


Figure 9: PRISMA flow chart for compost, municipal solid and hazardous waste papers

*The figure shows the screening process used by the authors to identify the final articles to be included in the systematic review. *Not relevant includes non-human or exposure studies, and those not conducted in the composting sector.*

The table below summarises the main findings from the 30 papers included in the review. Systematic or narrative reviews of the literature are presented first, along with the main conclusions and quality rating as using the SIGN grading system. These are followed by the longitudinal and cross-sectional studies of occupational illness. Finally, published case studies of work-related illness in compost workers are included at the end of the table. A narrative discussion of the clinically and occupationally important findings from the review follows.

Systematic and Narrative Reviews	*Topic*	*Main Conclusions*	*Quality Rating SIGN*
Pearson et al, 2015	Exposures and health outcomes in workers and residents in relation to emissions from composting facilities	66 studies, mainly cross-sectional. Bioaerosol concentrations highest on-site during agitation activities (turning, shredding and screening). Sampling generally short-term and number of workers generally small. Only one longitudinal study. Occupational studies suggest a higher risk of respiratory illnesses with higher bioaerosols exposures. Need for more objective measures of health effects.	2++
Searl & Crawford, 2012	Health risks in waste and recycling	Increased risk of ill health related to specific activities and exposure to bioaerosols. Use of agency workers, poor personal hygiene and failure to follow safe working procedures are relevant to causation.	2++
Binion & Gutberlet, 2012	Review of the wellbeing of recyclers	Poor working conditions, poor health, the need for worker co-operatives and the enforcement of health protection policies are discussed	4
Porta et al, 2009	Health effects associated with the management of solid waste	The evidence suggests an association but is not sufficient to establish a causal relationship between exposure and health effects	2++
Giusti, 2009	The impact of waste management practices on health	High prevalence of fatal and non-fatal accidents. Review included exposure to bioaerosols from sewage treatment plants and the effects on health of residents living near recycling plants. A request for better quality cohort studies with exposure measurements was made.	4
Domingo & Nadal, 2009	Health risks from domestic	Control of biological hazards, workplace measurements of microorganisms and	

	composting facilities	VOCs, PPE, analysis of compost for biological and chemical agents before agricultural application and the importance of health surveillance.	4
Fleming et al, 2002	Occupational exposures and health risks in solid waste workers	Solid waste workers experience acute and chronic musculoskeletal, dermal and respiratory health effects	2++
Poulsen et al, 1995	Occupational health problems in domestic waste collection and their causes	Increased risk of accidents, musculoskeletal, gastrointestinal, eye and skin problems; chronic bronchitis and organic dust toxic syndrome. There is a need to link exposures to occupational health problems.	4

Cross-Sectional And Longitudinal Studies	*Topic*	*Sample*	*Main Findings*	*Quality Rating Newcastle-Ottawa (0-10)*
Heldal et al, 2015	Work-related cough and lung function	47 compost workers, 37 controls in Norway	Actinomycetes spp. spore count was associated with work-related cough and cross-shift decrease in FEV1/FVC%	9
Schantora et al, 2015	Upper and lower airway symptoms, lung function tests	69 waste collectors in Germany	Rhinitis and cough positively associated. Prevalence of cough and chronic bronchitis not associated with duration of employment	6
Garrido et al, 2015	Health status and health-related quality of life (HRQoL)	63 municipal waste collectors in Germany	67% of collectors reported back pain which were associated with impairments in HRQoL scores	3

Hoffmeyer et al, 2014	Rhinoconjunctivitis and lower airway disease	190 current and 59 former compost workers in Germany	Eye and nose irritation not due to atopy. Chronic bronchitis in former workers probably due to chronic irritation from bioaerosol	9
Van Kampen et al, 2012	Respiratory symptoms, spirometry, specific IgE/G to fungi and Actinomycetes spp.	190 current, 59 former compost workers, 38 controls in Germany	Higher prevalence of conjunctivitis in current workers compared to controls. 75% of symptoms improved or disappeared after leaving composting. Cough and dyspnoea persisted in 39% and 20% respectively of former workers. %FVC reduced in compost workers. No difference in IgG or IgE antibody levels	8
Hambach et al, 2012	Work-related health symptoms	31 compost workers, 31 controls in Belgium	Higher prevalence of respiratory, gastrointestinal and skin complaints in compost workers	8
Athanasiou et al, 2010	Respiratory symptoms and lung function	104 domestic waste workers, 80 controls in Greece	Increased cough and sore throats and reduced FVC in waste workers	6
Bunger et al, 2007	Respiratory disorders and lung function in compost workers with 5 years of follow-up	123 compost workers, 48 controls in Germany	Higher prevalence of conjunctivitis and chronic bronchitis in compost workers. Significant FVC% decline in non-smoking compost workers compared to controls	9

De Meer et al, 2007	Methacholine responsiveness over the working week	Six cases with and 10 controls without respiratory symptoms who loaded domestic waste in The Netherlands	Methacholine responsiveness increased over the working week in subjects but not controls. There was no change in other lung function tests.	5
Poulsen et al 1995	Symptoms and exposure to bioaerosols	22 domestic waste workers in Norway	Increased nasal irritation with exposure to bacteria; increased cough with exposure to fungi	5
Heldal et al, 2003	Lung function and inflammatory markers in food and garden waste collectors	22 domestic waste collectors in Norway	Increased neutrophils and interleukin-8 in sputum and reduced lung function cross-shift. Inflammatory response correlated with endotoxin levels (r=0.55)	5
Wouters et al, 2002	Respiratory Symptoms, Upper airway inflammation.	47 waste collectors, 15 controls in The Netherlands	Prevalence of respiratory symptoms higher in collectors and associated with increased concentrations of neutrophils and IL-8 in nasal fluid	9
Bunger et al, 2000	Health complaints and immunological markers	58 compost workers, 53 collectors 40 controls in Germany	Compost workers had higher prevalence of respiratory and skin complaints than other groups, as well as higher IgG concentrations against fungi and Actinomycetes spp.	9
Ivens et al, 1999	Gastro-intestinal symptoms and relationship with	1747 domestic waste collectors, 1111	Increased self-reported nausea and diarrhoea with increasing	

	bioaerosols exposures	controls in Denmark	exposures to endotoxins and fungi.	9
Ivens et al, 1997	Occupational injuries	667 domestic waste collectors in Denmark	17% of employees experienced injury. Number of injuries decreased with experience	8
Hansen et al, 1997	Respiratory symptoms and relationship to exposure to bioaerosols	1515 waste collectors, 423 controls in Denmark	Waste collectors had significantly higher prevalence of cough, nasal irritation, wheeze and chronic bronchitis. Prevalence of chronic bronchitis was associated with high exposure to total microorganisms and fungi	6
Coenen et al, 1997	Respiratory symptoms, lung function and sensitisation to moulds	63 domestic waste collectors in Denmark	Increased MMI symptoms in collectors of garden waste; increased variability of peak flow in those with high exposure to *A.fumigatus*; increased IgG levels in those with high exposure to endotoxins	3

Case Studies	*Main Findings*	*Quality Rating* *SIGN*
Alonso E et al, 2015	Outbreak of Q-Fever affecting 62 employees at a waste sorting plant in Bilbao, Spain	3
Poole & Wong, 2013	2 cases of ABPA in municipal garden waste collectors in UK	3
Bunger et al, 2007	3 cases of EAA in compost workers in Germany	3

Allmers et al, 2000	1 case of OA and ABPA in a municipal waste collector in Germany	3
Anon, 2009	Asphyxiation of two workers by hydrogen sulphide gas from rotting animal waste in Scotland	3

Table 6: Composting, Municipal Solid and Toxic Waste Health Studies

The table summarises the main systematic and narrative reviews, cross-sectional and longitudinal studies, as well as case reports identified in this systematic review of occupational illness in the waste and recycling sector. Studies have been graded according to quality using appropriate classification systems by both authors, with the final score attained through mutual agreement where there were discrepancies.

Several papers noted that the highest exposures to bioaerosols and volatile organic compounds (mainly terpenoids and alcohols) are found to be in sorting stations during the turning, shredding or screening of compost or biomass. Maximum concentrations of total micro-organisms, moulds and endotoxins were during the summer months (Domingo & Nadal 2009; Pearson et al 2015). At subclinical level, increased inflammatory or immunological markers such as neutrophils, interleukin-6 or -8 and immunoglobulins have been found in the nasal fluid, sputum, breath condensate or the serum of compost workers. These markers have correlated to reported symptoms and recorded exposure to endotoxins and beta-glucans (Wouters et al 2002; Heldal et al 2003). Sensitisation to components of bioaerosol such as *Aspergillus fumigatus* and *Actinomycetes spp.* has been identified in serum of workers but fewer have examined sensitisation by skin prick testing. Although raised levels of serum IgG to fungi have been reported, the largest study to date found no difference in total IgE or prevalence of sensitisation to fungi between compost workers and controls (Van Kampen et al 2012). There was one longitudinal German study which shows declining FVC% greater than controls (Bunger et al 2007).).

With respect to clinical symptoms, several cross-sectional studies have reported increased ocular, nasal, respiratory, skin and gastro-intestinal symptoms (Bunger et al 2007; Hambach et al 2012; Van Kampen et al 2012). A few authors have suggested a dose-response effect for health effects however, based on a systematic review, a bioaerosols expert network concluded that there is currently insufficient evidence to derive health-based exposure limits (Walser et al 2015). There were also reports of adaptation by some workers to the acute effects of exposure or a healthy worker effect. Although reviews referred to organic dust toxic syndrome because of exposure to bioaerosol, there were no case reports of this in compost workers. There were comparatively fewer reports of established occupational disease in the form of clinical syndromes. There were a few case reports of allergic disease such as hypersensitivity pneumonitis (extrinsic allergic alveolitis), allergic bronchopulmonary aspergillosis and occupational asthma (Bunger et al 2007; Poole & Wong 2013)

Aside from respiratory complaints, illness and injury relating to other occupational hazards in the composting sector were noted. Four papers reported increased accident rates and musculoskeletal injuries in refuse workers compared with controls or the general working population, with injuries mainly affecting the hands, arms, back or shoulders. It has been suggested that the use of two or four-wheeled containers instead of sacks has given rise to more shoulder and arm injuries but fewer back injuries (Kuijer & Frings-Dresen 2004). Although *Legionella pneumophilia* and *Legionella longbeachae* may be found in compost, there were no reports of Legionnaire's disease in these workers (Walser et al 2015). An outbreak of Q fever due to *Coxiella burnetii* in at least 50 workers was reported from a site that was probably contaminated with animal carcasses (Alonso et al 2015). Asphyxiation of two workers by hydrogen sulphide from rotting animal waste was reported. The importance of personal protective equipment has been stressed, but cabs must be well maintained, and windows kept closed and components of the bioaerosols have been found on the inside of respiratory protective equipment

2.4. Discussion

This systematic review has identified that compost workers are exposed to elevated levels of bioaerosol as compared to the general population, particularly those of fungi, bacteria and their constituent components. Sensitisation to bioaerosol components has been identified in the workforce. There are high quality data from several studies referenced in Table 5 (SIGN 2++; NOS 8/9) showing that such exposures may be associated with mucosal membrane and respiratory irritation as well as abnormal lung function tests, bronchial hyper-reactivity and increased inflammatory markers in nasal fluid, sputum or serum. There are some case reports of occupational disease in the sector such as EAA and ABPA, but these are relatively few.

This is the first attempt to collect and review the health effects of occupational exposures for compost workers. Our findings suggest a significant burden of work-related symptoms in the sector, but a number of important questions remain for which the answers would inform the clinical and occupational management of workers. For example, sensitisation to *Aspergillus fumigatus,* other moulds and *Actinomycetes spp.* has been found, but whether these workers are predisposed to developing occupational illness in comparison to their non-sensitised counterparts is unclear. Some studies suggest a dose-response health effect in compost workers, but a review of the evidence concluded that there is not strong enough evidence to set exposure limits (Walser et al 2015). Thus, there is a need for further work to examine the relationships between exposures and symptoms. This includes examining the latency between the development of subclinical markers of inflammation and the onset of symptoms and disease.

Despite these unanswered issues, the findings from this review indicate that compost workers are at an increased risk of occupational illness for which regular health surveillance and pre-employment screening should be considered. The optimal methods for health surveillance in this sector are unknown, but may include a health questionnaire, serial peak flow diary, longitudinal spirometry, SPTs and serum specific IgE. Additional care with the medical vulnerable, such as immunosuppressed individuals or those with severe underlying lung conditions may be warranted. Whilst respiratory symptoms and illness have most commonly been reported, case reports of gastrointestinal and skin complaints merit further study and may inform, for example, the inclusion of skin assessment within a health surveillance programme for workers in this sector. Appropriate health surveillance should be determined based on a suitable and sufficient risk assessment that is likely to include environmental measurements, biological monitoring and the findings of literature reviews such as this one.

There are several limitations of this review. Firstly, most research in the waste and recycling sector has been directed at large, industrial scale composting activities. It is possible that work practices are more stringent in such settings. Thus, the burden of occupational illness may be more significant at smaller sites where controls to exposure may be less rigorous. In addition, a common limitation to all studies in this review is the possibility of the underreporting of symptoms given the implications this could have for workers' tenure. For instance, this may at least partly explain the relatively few reports of established illness in the sector thus far. Other limitations of this review include the small numbers of cases that were identified by the UK's regulatory (RIDDOR) and national surveillance (THOR) schemes. Of those that were identified very few, if any, appear to have been reported in the scientific literature. Furthermore, the rigor by which diagnoses and attribution of the cases that were reported was established is unknown. That is, it is likely that much work-related illness went uncaptured by these schemes and by the peer reviewed literature. The quality of controls to contain the bioaerosols or limit the exposure of workers using air-conditioned vehicles or personal protective equipment is unclear and may not be effective due to problems with compliance and maintenance.

Methodological limitations include the absence of an established grading system for cross-sectional studies I used a modified version of the Newcastle-Ottawa Scale (NOS) to score them in a systematic way. Although the NOS has been criticized for lacking an evidence base for case-control and cohort studies (Stang 2010), it has been used for several other systematic reviews of cross-sectional studies. Assessing the quality of the papers in the non-composting industries in a systematic way was not undertaken as they were relatively few and outside the scope of focus of this thesis. The geographical variations in the way that these industries operate, and the adequacy of controls will in part determine what health effects may occur.

The next chapter of this thesis describe the planning and preparation for a cross-sectional study of occupational illness in the UK composting sector, including the recruitment of companies and their workers into the project and ethical considerations.

Chapter 3: Recruitment and Ethics

3.1. Recruitment

This study was developed in response to concerns raised by some industry representatives and health professionals regarding the potential for adverse health effects arising from occupational exposure to bioaerosols. To this end, I developed this project with the Health and Safety Laboratories, Buxton, England in 2014. I was aware at an early stage that the proposed project, although of prospective scientific value, may cause concern amongst company managers and trade unions. Such concerns might include the business impact of taking workers out of their job to participate; finding individuals with illnesses or personal vulnerabilities that could affect their employment or identifying health problems which could lead to compensation claims.

Accordingly, I undertook the following preparatory work to obtain the support of relevant stakeholders to carry out the research. Having gained ethical approval for the study, I contacted trade union representatives at the Renewable Energy Association (REA) in the UK to promote the study amongst the Organics Recycling Group (ORG) sector of the organisation. The REA assisted me with advertising the study to its members which comprised about 1000 organisations at the time, including several large composting companies. Following discussion with the Technical Director at the REA, the following took place:

- I presented a synopsis of the planned study at an ORG conference in late 2014, which was attended by several company directors and safety managers from across the UK. A copy of this presentation is found in the Appendix of this thesis.

- I placed the following extract on the REA website and the organisation's monthly magazine 'Let's Recycle'. The extract is available at http://www.organics recycling.org.uk/page.php?article=2981&name=Call+for+volunteers+for+bioaerosols+st udy

Compost Workers Health Survey

The Organics Recycling Group has been asked to help with medical research into the health of workers on compost sites. The information below has been provided by the research team and we would ask that interested members contact either of the medical staff named for further details of the research.

Research overview and call for volunteers

There are an increasing number of medical reports of ill health due to exposure to garden waste or compost. My research hopes to examine how common work-related illness is in the industry, and if relevant, the factors that may be contributing to this. The aim is to inform occupational health surveillance for the industry. I would like to carry out a study of compost workers to answer these questions. To complete the project, we need composting companies to support this research by allowing us to ask their workers to complete a questionnaire and for workers to agree to give voluntary samples for analysis. This should take no more than 20 minutes of their time. I would like to recruit at least 100 workers and so far, one company with 40 workers has agreed to take part. I have a scientific protocol which I shall share with participating companies and I have ethical consent to do this work. I am happy to acknowledge the contribution of each company in any scientific publication that might arise from this research.

If your company is interested in taking part, please contact Dr Subhashis Basu at Subhashis.basu@sth.nhs.uk.

Figure 10: Extract from ORG Website and LetsRecycle Magazine

I created a short advert to advertise the study to industrial composting companies which were members of the Organics Recycling Group sector of the Renewable Energy Association trade union in the United Kingdom, in response to concerns amongst industry safety managers about the health effects of bioaerosol exposure.

I received interest from seven large and medium-sized composting companies in England. Another company based in Northern Ireland also indicated a desire to take part, but restrictions on funding precluded their involvement. Each company safety manager received a copy of the study protocol; project consent forms and volunteer information sheet (see Appendix for details).

In the following weeks, I met with the safety manager of each company to clarify information in the project protocol, answer any further queries, and determine an appropriate timescale for conducting the work in their company. Participants were volunteer workers from each of the companies involved. All site workers, including office staff, were invited to take part. The site managers discussed the project with their workers prior to site visits and provided them with the study documents including the project protocol. My contact details were also provided for any questions the workers might have had. Safety managers were provided a list of medications that could interfere with the SPT reading and were asked to inform potential participants not to take these for a period of 24 hours prior to conducting the test, unless there was a specific medical indication as to why this was not possible. All the company managers also agreed to share exposure data they had collected and agreed for exposure studies to take place should there be enough funding available.

3.2. Site Descriptions

Of the six companies involved in the study, three used solely open-windrow facilities; two uniquely indoor IVC facilities, and one company a mixture. Company number 1 was a family-run business operating on a single large open-window facility employing 17 workers. Management had taken recent static and personal dosimetry measurements of *Aspergillus fumigatus* and total dust exposure during a working day, but none were specific to any known high-exposure tasks such as screening, shredding and turning. The company had recently purchased health surveillance provision, but none had been conducted by the time of my visit in July 2015. The second company operated several open-windrow and IVC sites across the country. I was able to access two sites in the locality, both of which were IVC sites employing 15 workers in total. I was also given the contact details for a third site in the north-east of England owned by the company which agreed to take part and employed 9 workers. The third company which took part in the study did so on the recommendations of the positive experience of the second. This company employed several contractors to sites owned by other companies across the Midlands. I was given access to three open windrow sites employing 14 workers in total.

The fourth company that agreed to participate did so in response to the project advertisement placed in the LetsRecycle magazine and operated 6 open-windrow sites with a total of 50 workers. Four of these were mixed recycling sites, in that other materials such as plastics and household waste were also processed. One was also located close to a waste-water treatment facility. The area manager for this company put me in touch with a fifth company that agreed to take part in the study based in the north east of England. This site employed 10 workers and was an open-windrow facility. Finally, I directly contacted a sixth company to take part in the study which operates numerous IVC sites across the middle and south of England. One site which employed 14 workers agreed to take part. Two further companies had also shown interest in the study, with one having agreed to participate but becoming insolvent by the time of data collection. A further large waste company subsequently declined to take part due to restructuring of their operations, but their safety manager provided substantial help in the design of the questionnaire to ensure it would be appropriate for the workforce. Each company used similar operating processes, practices and procedures across all owned sites. The design and layout of sites were also generally similar. Accordingly, I have summarised these in the table below, with important differences between sites noted at the relevant stage. It should be noted that the land requirements for windrow sites were considerably greater (at least 50000 m^2) than for IVC sites (approximately 20000 m^2).

Company	Site Characteristics
1	Large open-windrow in-land composting facility. Single site facility receiving source-separated waste. Weighbridge situated >500metres from nearest windrow. Capacity of six windrows (piles of compost) total turned weekly. Wood also recycled on-site, approximately 500 metres away from nearest windrow. Office buildings >500 metres from compost.
2	IVC only. Residual waste separated from composting material on site manually. Separated shredding and screening halls linked by an open portal through which material transferred by a front-end loading tractor. Capacity to lay compost material in up to six IVC tunnels for maturation (site one) and five tunnels (site two). Office buildings >500 metres from compost.
3	Three large open-windrow sites based in central England. Weighbridges situated within 250 metres of nearest compost pile on all sites. In one facility, all buildings situated within HSE Green Zone (100-250 metres). Maximum windrow capacity between 4-8 on each site. Residual waste removed manually prior to shredding. Office buildings >500 metres from compost.
4	Six open windrow sites located in-land of variable size (medium to large). Two facilities managed other types of recyclable waste including paper and plastic. Another facility recycled wood, with the wood pile located approximately 500 metres from nearest adjacent windrow. A separate facility managed sewage, with the sewage work located approximately 1km from the weighbridge. Weighbridge distances from nearest windrow varied from approximately 150-500 metres. Residual waste material separated on sit from compost pile manually. Office buildings >500 metres from compost.
5	Large open-windrow composting facility based by the North-East Coast of England. Compost-only site. Residual waste separated from composting material separated on site manually. Weighbridge situated >500metres from nearest windrow. Maximum capacity of ten windrows, turned every 7-10 days. Office buildings >500 metres from compost.
6	Single IVC site with separated shredding and screening halls. Compost-only site. Up to 8 tunnels maximum capacity. Residual waste separated on site from composting material manually. Office buildings >500 metres from compost.

Table 7: Site Descriptions

3.3. Ethics and Governance

The study was ethically approved by the National Research Ethics Service North West Ethics Committee. The Research Ethics Committee reference for the study was 14/NW/0188**.** Consenting participants were provided with a unique identifying code (a set of three numbers) at the beginning of the study. This code was created to ensure the anonymity of results, whilst allowing data linkage to provide feedback to participants. Only I had access to the unique identifier.

Participants' completed questionnaires were stored in a secure filing cabinet at the Health and Safety Laboratory as per the organisation's data governance policy. Test results for SPTs and blood samples were stored on a secure, password-protected memory stick certified for use at the Health and Safety Laboratory, for which the access password was known only to me. In keeping the requirements of the ethics committee and with the participant's consent, each worker's GP was informed of their involvement in the study.

Workers were sent a copy of the project information sheet prior to my visit and afforded a further opportunity to discuss aspects of the study with me in person before the study commenced. I gained informed consent from each participant on site before completing the questionnaire and conducting the tests. Both the information sheet and consent form are included in the Appendix section of this thesis. Participants were told that should they wish to withdraw from the study or become otherwise incapacitated that their data would be destroyed.

The way in which the results were communicated to workers, employers and their GP was agreed by the ethics committee. Management was provided with anonymised, grouped data to include the number of workers reporting work-related symptoms and the prevalence of sensitisation. It was recognised that individual workers may wish to discuss their results with management, and thus I discussed the implications of the results in general terms with management before they were communicated to the employees. Employers were able to contact me for specific advice about the study and its findings, but not for individuals' results unless the worker had previously shared their results with them or consented for me to do so on their behalf.

Workers received a letter containing their skin and blood results, and a summary of the results of the whole study. Workers were advised that they could discuss their results with management and with me should they need to. Volunteers were provided with an email address and telephone number to contact me. An individual that was sensitised to moulds or bacteria via SPT or IgE seropositivity, immunosuppressed, atopic or medically vulnerable due to pre-existing lung disease (such as cystic fibrosis, bronchiectasis or asthma) was advised of a possible risk of additional lung disease. Any worker who was sensitised and symptomatic for occupational lung disease was alerted immediately by letter. A letter was also sent to their GP and/or their specialist with the worker's consent to this effect.

Chapter 4: Exposure Studies

4.1. Introduction

The data provided in this chapter provides a context to interpret findings from the cross-sectional health study which follows later. Understanding exposure-health responses is also a prerequisite to deriving occupational exposure limits. Whilst this is beyond the scope of this thesis, I shall also later describe how this could be approached. The chapter begins with a discussion of the strengths and weaknesses of existing bioaerosol collection methods and the approaches to enumerate collected microorganisms. Accordingly, I shall then describe my approach to collecting and analysing bioaerosol data from one indoor IVC and one outdoor windrow site. This will be followed by a description of the results from each site, and discussion of the relevance of the findings with comparison drawn with prior research in the field.

My role in this work was to arrange the site visits; ensure that sampling was conducted in an appropriate manner and for the outdoor site, in appropriate weather conditions; liaise with scientists at the Health and Safety Laboratory to assist with data collection and analysis; help setup bioaerosol monitoring equipment on site; assist with data analysis and microbial identification as well as write up the final reports for the companies concerned.

4.1.2. Sampling Approaches

The main constituent bioaerosol agents within compost and their associated health effects have been described earlier. This section covers bioaerosol monitoring methods in more detail including an evaluation of their strengths and weaknesses. Techniques include direct impaction, impingement, filtration, electrostatic precipitation and sedimentation.

Direct impaction uses inertial forces to collect particles in air. Air is drawn through an impaction sampler and forced to change direction using a pump (Gilbert & Ward 1999). A common impaction device is the Anderson sampler of which there are several types. These include six-stage, two and single-stage samplers, with each stage capturing particles of different sizes as they pass through the sampler. Air flow rates and the number of collection chambers can be altered to collect different sized particles.

Image *4: Two-Stage Anderson Sampler*

Air passes through the sampling head with particles deposited at two levels in the sampler, with smaller particles captured in the lower level. The sampler operates at a high flow rate of 28.3 litres/minute

Microorganisms are deposited onto a glass slide or a semi-solid agar plate. Using agar plates is advantageous since collected microorganisms are cultured and then counted directly, eliminating the need for further post-sampling processing other than incubation at the required temperature. Nonetheless, these plates may be overloaded with microorganisms particularly during longer sampling periods or at high bioaerosol concentrations, thus making the counting process difficult as colonies overlap. It has been recommended therefore that if high levels of bioaerosol are expected, such as in intense compost agitation activities, the sampling time should be shortened accordingly. Additionally, the physical stress that occurs when microorganisms are deposited on the agar plate may lead to fragmentation, with some becoming non-culturable thus underestimating true colony counts (Li & Lin 1999). Wind speed at the inlet has been shown to affect collection efficiency.

Impingement methods are similar to impaction methods except that microorganisms are collected into a liquid medium. Most are made of glass, but these may break in the field. Metal samplers made of aluminium or stainless steel are available, but these are more expensive. As with impaction methods, single and multi-stage samplers are available. Various liquid collection mediums are used such as Ringer's solution, betaine and peptone, and their purpose is to reduce osmotic stress on the microorganisms after collection. Although impingement systems in general place less physical stress on microorganisms than impaction methods, losses through physical destruction of organisms have still been reported (Pillai & Ricke 2002). Some authors have reported that liquid collection methods may be less suitable for fungal spores than bacteria, as most fungi are hydrophobic and are therefore recirculated and lost in airflow (Willeke et al 1998).

Filtration sampling is a cheap and effective means of collecting bioaerosols. This works using particle inertia and diffusion but does not capture information about particle size. This method is most often used for personal monitoring but can be utilised for static sampling to give an overview of microbial exposures. It has been shown previously that microbial counts captured by impaction methods are higher than those recorded by filter systems. This suggests that filters may be less suitable for more detailed sampling as required, for example, by the Environment Agency's standard protocol (Predicala et al 2002). As with agar plates in impaction methods, filters may also be overloaded with microorganisms in highly contaminated environments, leading to difficulty in enumeration post-collection. Desiccation, particularly of Gram-negative bacteria has been reported over prolonged sampling times or in humid environments (Wang et al 2001).

Cyclone systems collect microorganisms in a liquid medium and have similar efficiencies to impingement methods. There is some evidence that particle loss due to re-entry into the airflow pathway is lower using cyclones than liquid impingement methods. Nonetheless, liquid losses due to evaporation may be higher (Henningson & Ahlberg 1994). Electrostatic precipitators work by applying a high voltage to surrounding air thus ionising certain particles which are attracted to plates. The method is particularly useful in capturing ultrafine particles, such as nanoparticles which can be subsequently analysed by electron microscopy. Another advantage of this approach is a reduction in physical stress incurred by microorganisms through the collection process. Liquid and solid collection mediums can be used, but liquid substrates are thought to have lower recovery efficiencies as compared to solid mediums such as agar (Mainelis et al 1999). Finally, hybrid samplers combining one or more of the approaches described above are also available, such as the Virtual Impactor which combines electrostatic precipitation and impaction.

The following table is extracted from a publication by the Environment Agency entitled "*Review of methods to measure bioaerosols from composting sites*" (Cartwright et al 2009). I have included an abridged version here because it neatly summarises the strengths and weaknesses of the main bioaerosol collection methods.

Collection Method	Advantage	Disadvantage
Impaction	Direct collection of micro-organisms onto culture medium. Robust performance data Can process multiple samples without sterilisation	Restricted to just culture-based enumeration methods Risk of overloading culture plate Wind speeds affects accuracy
Impingement	No overload of collection medium Better survival of collected micro-organisms in liquid rather than solid collection medium No restriction on subsequent enumeration methods used Robust performance data	Samples require further processing post-collection Glass impingers may break Loss of collection liquid through evaporation Will require sterilisation between samples Wind speeds affect collection
Filtration	Easy to use. No restriction on subsequent enumeration methods used	Desiccation of micro-organisms on filter Further processing post-collection before numbers can be quantified Risk of overloading the filter Wind effects on sampling efficiencies
Cyclone	Good collection efficiency due to reduced loss through re-entrainment Easy to sterilise	Problem of loss of collection liquid through evaporation Limited efficacy data
Electrostatic precipitation	Good recovery efficiency due to reduced stress on the micro-organisms during collection	Limited efficacy data

Table 8: Summary of Bioaerosol Collection Methods

The table describe the main approaches used to examine bioaerosol exposures including their advantages and drawbacks when interpreting data. The main established methods include direct impaction on to a solid medium, impingement into a liquid medium and filtration. Newer methods such as the cyclone approach and electrostatic precipitation have limited efficacy data.

4.1.3. Determination of Bioaerosol Counts

The enumeration of bioaerosols can be achieved using direct and indirect approaches. Direct counting methods are performed by spreading a measured volume over a plate or slide, counting representative microscopic fields, and applying appropriate volume-area factors to provide average values. A modified direct counting approach is the use of fluorescent dyes to stain certain species or cell components, particularly when there are several metabolically similar species in a sample which preclude direct observation under a microscope or assessment using an electronic counting device (Crook & Sherwood-Higham 1997). Although a rapid process, a known limitation of direct counting methods is an inability to distinguish between living and dead cells (Eversole et al 2001). The fluorochrome stains used such as acridine orange and 3,6-bisdimethylaminoacridinium chloride may also bind to organic material in soil and sediment. This non-specific binding may be a difficulty in composting, because samples generally contain high volumes of other organic matter.

Indirect counting methods involve diluting and growing samples in an appropriate medium. The growth in the medium is used to estimate numbers in the original sample. The viable plate approach is the most commonly used indirect counting method, in which serial dilutions of a sample containing microorganisms of interest are spread or poured into a plate. Microorganisms are grown in controlled environmental conditions according to the species under study. Nonetheless, non-viable organisms may not be counted, leading to an underestimation of total concentrations (Pillai & Riche 2002). These limitations can be addressed by selecting appropriate growth media for the range of microorganisms under study and understanding the number of colonies likely to be collected per Petri dish since more than 300 may cause overloading (Chang et al 1995). This approach has also been deemed satisfactory for the enumeration of bioaerosols collected from compost (Environment Agency 2009). A variation on this approach is most probable number (MPN) counting which quantifies the number of microorganisms in liquid samples without counting. Once again, serial dilutions are used but in this technique to the point where no microorganisms are present. Statistical tables are used to determine actual numbers, and the use of a liquid culture reduces physical stress which may damage samples, thereby improving estimates. Another indirect enumeration approach is to measure microbial biomass using relatively constant biomarkers in the microorganism pool. These include cell components such as proteins, peptidoglycans, fatty acids or cell products such as endotoxins (lipopolysaccharides). False positives from substances such as glucans may occur when using the Limulus Amoebocyte Lysate (LAL) assay to measure endotoxin from Gram-negative bacteria, and non-specific dusts may also interfere.

Molecular-based analytical methods can also be used to detect microorganisms. A standard approach is the use of polymerase chain reaction (PCR) assays. PCR uses primers that are approximately 20-30 nucleotides in length to amplify the DNA in target organisms and thus are less prone to false positives than other approaches. Since target DNA can be amplified rapidly, up to 1-million-fold in 60 minutes, and quantitative PCR assays can isolate a single antigen, these methods can be used to identify pathogens in large systems such as water and food (Yoo et al 2017). Living and dead microorganisms can be counted, and the nucleic acid-based technique can provide quantitative information on numbers of specific micro-organisms. Though costly, these methods are quick, specific and sensitive. Limitations of molecular analysis methods include the use of adenosine triphosphate as an indicator of metabolic activity, as there is no direct relationship between adenosine triphosphate levels and numbers of microorganisms. Expected differences in metabolic activity between microbes released from compost and background flora raise further concerns about the suitability of this method in green waste settings (Crook and Sherwood-Higham 1997).

4.1.4. Hypothesis, Aims and Objectives

My hypothesis was that concentrations of measured bioaerosols and total dust would be higher in the indoor than the outdoor windrow site. The rationale for this was that higher wind velocity and the open space would aid the dispersal of bioaerosol in an outdoor environment. Additionally, I expected conditions to be hotter and more humid in an indoor environment thus favouring the production of greater concentrations of *Aspergillus fumigatus* and *Actinomycetes spp*. Indeed, an earlier Norwegian study (Heldal et al 2015) had identified higher concentrations of *Actinomycetes spp.* in indoor facilities. Accordingly, the aims of this project were to:

1. Determine total dust and bioaerosol concentrations produced from industrial composting activities at one indoor (IVC) and one outdoor (windrow) site using culture-based direct counting methods.

2. Assess whether the bioaerosol emissions from the two sampled sites in this study were consistent with levels previously recorded in the literature.

Additionally, I wanted to:

1. Produce a sample set for future analysis to compare findings from standard culture methods with those of DNA-sequencing approaches.

2. Add to the existing evidence base held by the Health and Safety Executive in the United Kingdom about ambient concentrations of bioaerosols in the green waste industry.

4.2. Methods

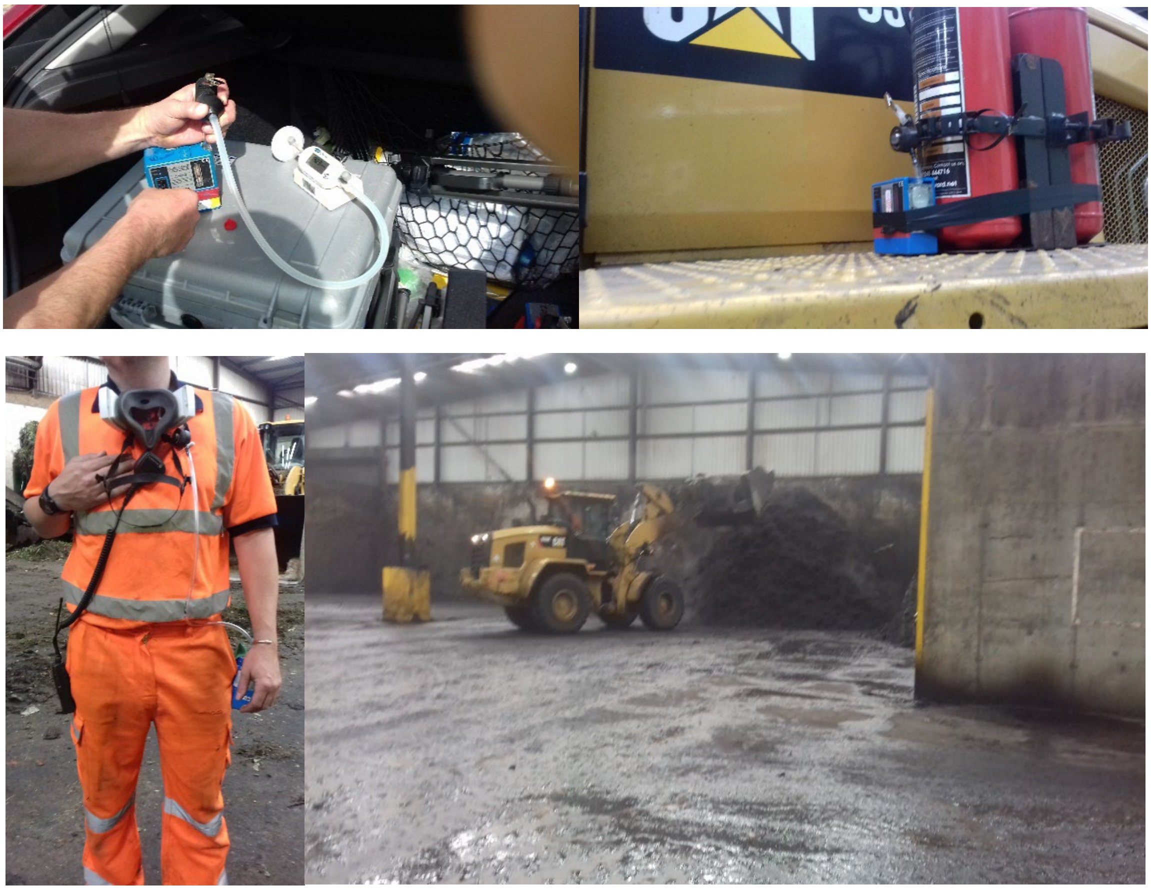
4.2.1. Indoor Site

I conducted bioaerosol monitoring at one of the IVC sites in this study with the support of two microbiologists from the Health and Safety Laboratory, Buxton, England in July 2017. Arrangements to conduct the work were made through the local site manager. Clearance was provided by senior company staff provided that their organisation would not be named in any subsequent publications and could not be identified from the data, including photographs, taken by us. The site manager arranged for shredding activities to take place during our sampling timeframe.

The IVC site involved had two main compost piles of interest. The first was in the reception hall to which green waste is delivered. Here, litter was picked manually from the compost pile. The compost was then delivered through a connecting window to a separate hall in which shredding activities took place. Two operatives worked in the delivery hall, one of which was a litter picker who wore an air-fed breathing apparatus as RPE. The other was based in a positive-pressured filtered cab to transport the compost to the pre-treatment for shredding, with windows and doors shut. A single operative was based in the processing hall who also drove a positive-pressured cab to load compost onto the shredder.

Sixteen bioaerosol samples were taken to ensure adequate site coverage, and this number was based on professional advice from experts based the HSE Laboratories, Buxton, England, two of whom accompanied me to both site visits and had *a priori* knowledge of the layout of the facilities. Samples were collected using glass fibre filters mounted in IOM sampling heads, with a flow rate of 2 litres/minute. The IOM head is a conductive plastic sampling head encased in a reusable cassette which collects airborne particles onto a filter. The IOM sampler used traps particles up to 100μm in diameter, thus capturing inhalable dust but not a respirable fraction. It works similarly to the way in which a human nose and mouth inhales dust. The utility of the IOM sampler in this context is already established (Environment Agency 2010).

I placed several static samplers in a rectangular pattern as close to 10 metres from each compost pile as possible. A sampler was also attached to the outside of each cab using a plastic tie. One sampler was also placed on the outside of each building, with another placed opposite the waste entrance to the delivery hall. The specific locations are documented in the results tables below. Sampling took place over a four-hour period. All three workers agreed to wear personal samplers which were attached to the front of their work clothes (see images below), as well as personal sampling pumps which met the requirement of the relevant British Standard (BS EN ISo 13137). Each pump had an automatic flow control to maintain the volumetric rate at +/- 0.11 litres/min of the baseline in case of back pressure changes due to filter loading. Each pump also had a malfunction indicator to indicate interruptions in air flow. Environmental conditions were monitored to include temperature and relative humidity. All samplers were calibrated using a flow meter, also known as a rotameter, to provide a flow rate of 2 litres per minute of air. Flow was checked at two hours (halfway) into the sampling session. Pumps were battery-operated and checked prior to deployment. The lower limit of sampling detection was 0.044 mg. The filters used in this study were Quartz filters, (Whatman QM-A), determined by HSL and others in previous studies to be optimum for retrieval of captured micro-organisms and endotoxins (Kenny *et al* 1998; Reynolds *et al* 2002). All filters were weighed at the Health and Safety Laboratory prior to data collection.



Images 5-8: Indoor Compost Site Activities

The top left image 5 demonstrates the calibration of the pump using a rotameter set at 2litres/min. The top right image 6 shows where a static sampling IOM filter head was placed on the cab to capture emitted bioaerosols. The bottom left image 7 displays the position of the IOM filter on the worker, attached to the front of the chest using a lapel with the pump attached at the waist. The worker's RPE in the form of an air-fed mask is also shown. The bottom right image 8 shows the loading of material using a front-loading cab in preparation for shredding.

Image 9: Static monitoring
The image depicts an IOM filter with a pump (blue) set at a flow rate at 2L/min placed on a container approximately 10 metres from the compost pile.

4.2.2. Outdoor Site

I also conducted bioaerosol monitoring in August 2017 at one of the large outdoor sites owned by a company taking part in this study. Sampling practices mirrored those at the indoor site, once again over a period of four hours, with the same environmental measurements also recorded. Once again, I was accompanied by two microbiologists from the Health and Safety Laboratory, Buxton.

The site recycled green waste, with piles of green waste arranged into a series of open windrows for turning and compost production. The site manager kindly arranged for shredding activity to take place on the day of our assessment. Once again sixteen active IOM samplers were deployed of which one was placed on the outside of the cab; one worn by the driver, three facing the screener 20 metres downwind, three facing the screener 50 metres downwind, and others to the left and right of the screener at distance of 20-30 metres from the compost pile. Four control samples were also collected with three behind the screener 30 metres upwind, and one at the weighbridge approximately 500 metres away from the windrow.

The upwind and downwind sampling was conducted as part of a joint project with the Imperial College University, London, England to understand the value of Next Generation (*NextGen*) sequencing in bioaerosol monitoring. As discussed earlier, previous work has suggested that conventional analysis methods may underestimate total bioaerosol concentrations and associated health risks by only considering living microorganisms as potential pathogens. The findings from these different methods of analysis will form part of a subsequent publication from this work.

4.2.3. Sampling Preparation, Analysis and Enumeration

Samples were prepared according to HSE guidance MDHS 14/4. Filters and cassettes were weighed as a single unit prior to sampling and set up on-site in an uncontaminated environment, within 30 minutes of commencing data collection. All samples (control and non-control) were set-up, collected and analysed identically. At the end of the collection period, the IOM samplers were capped and transported to the Health and Safety Laboratory, Buxton for further analysis. The following day, the filters and cassettes were weighed as a single unit, and the change in weight from the start of the study gave the value for total particulates collected (mg). The value for total particulates was then divided by the volume of air sampled (litres x 1000) to provide a figure for airborne concentration in mg/m^3. The exposed filters were placed into 30ml sterilin pots and the collected deposits were extracted by slow centrifuge at room temperature for 2 hours in 10ml of ¼ strength Ringers solution. A dilution series (neat, 1 in 10, 1 in 100, 1 in 1000) was prepared from the initial extraction suspension and used to inoculate agar plates. The principle here was to create colony counts between 30-300 as this provides the greatest statistical accuracy when calculating colony forming units/ m^3. Accordingly, more concentrated samples underwent greater dilution. Plates were grown for 7-10 days at the following temperatures:

- 25°C to estimate total environmental fungal and bacterial counts
- 37°C to estimate counts for fungal and bacterial pathogens (body temperature)
- 40°C for thermophilic fungal counts (likely predominantly *Aspergillus fumigatus)*
- 55°C for thermophilic bacteria counts (predominantly *Actinomycetes*)

After counting, colonies were converted to cfu/ m^3 by taking account the volume (578 litres) in which they were grown.

4.3. Results

4.3.1. Indoor Site

The results from the IVC site are shown below. The first table displays airborne concentrations of total dust measured at each of the 16 sampling locations. The second table summarises the concentrations (cfu/m³) of fungi and bacteria at the different temperatures. Sampling time ranged from 268-280 minutes and flow rates for all sampling pumps were maintained between 1.950-2.000 litres per minute as per recommended guidelines. Four control samples were also tested as per laboratory protocol, with all particulate recordings <0.044 milligrams. The environmental measurements for temperature and humidity are shown in the graph below. The graph displays a spike in humidity at about 9.45am. This reflects a change from sensor measurements taken in the cooler and less humid delivery hall, to the relocation of the sensor to the screening hall in which temperatures averaged between 20-25°C with an average air humidity of just over 60%.

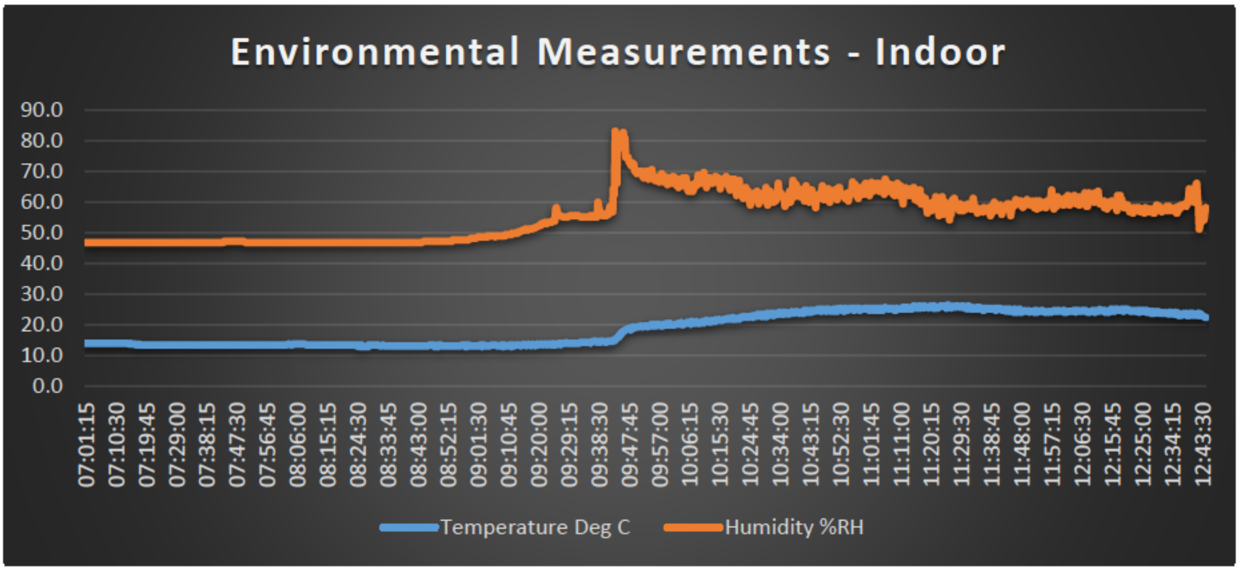


Image 10: Environmental Measurements in Indoor Facility

The graph shows temperature (blue line) and air humidity (orange line) recorded during the study period. Time is displayed along the x-axis with the environmental parameters along the y-axis. The spike in humidity and temperature at about 9.45am represents a change of setting from the delivery to the maturation hall.

The airborne concentrations of total dust at the indoor site were low in both buildings, with the highest readings recorded immediately next the screener as one would expect. Of interest are the personal exposures of the cab drivers and the litter picker in the delivery hall over the four-hour period. If the recorded measurements are converted into 8-hour time-weighted average, the values for the loader driver, screening cab operator and litter picker are 0.16, 0.10 and 0.33 mg/m^3 respectively. These values are below the 10 mg/m^3 workplace exposure limit for inhalable dust and 4 mg/m^3 limit for respirable dust specified under the Control of Substances Hazardous to Health Regulations 2002.

Filter Number	***Sample Details***	***Total Particulate (mg)***	***Airborne Concentration (mg/ m^3)***
1	Waste reception and shredding hall, near fire escape	0.133	0.230
2	Waste reception and shredding hall, to the right of oversized material	0.142	0.248
3	Waste reception and shredding hall, near green bin	0.104	0.188
4	Waste reception and shredding hall, left of oversized material	0.120	0.210
5	Waste reception and shredding hall, on loading shovel	0.446	0.838
6	Waste reception and shredding hall, personal loader driver	0.180	0.325
7	Waste reception and shredding hall, personal litter picker	0.357	0.662
8	Screen and maturation area, on central plinth	0.476	0.895

9	Screen and maturation area, middle of hall	0.236	0.443
10	Screen and maturation area, right of screener	0.436	0.776
11	Screen and maturation area, left of screener	0.322	0.574
12	Screen and maturation area, far side of hall away from screener	0.234	0.454
13	Screen and maturation area, personal driver	0.105	0.201
14	Screen and maturation area, outside of cab	0.466	0.936
15	Outside on corner of screener building	0.120	0.228
16	Outside opposite the waste entrance on skip	<0.044	<0.084

Table 9: Total Dust Measurements at Indoor Site

Measurements of total dust obtained from 16 samples placed at the IVC site over a four-hour period using IOM filter heads. Samples 6.7 and 13 were personal samples attached to workers in the manner described above. Total dust samples were converted to airborne concentrations using the calculations specified in the methods section.

Airborne concentrations of *Aspergillus fumigatus* were higher when shredding (10^{5-6}) as opposed to screening (10^3), whereas the reverse pattern was seen for *Thermophilic Actinomycetes*. A similar trend to that of *Aspergillus spp.* was observed for environmental fungi, and environmental/pathogenic bacterial generation patterns followed those of *Actinomycetes spp*.

Filter Number	*Sample Details*	**Environmental Fungi 25°C** *(cfu/ m³)*	**Environmental Bacteria 25°C** *(cfu/ m³)*	**Potential Pathogenic Bacteria 37°C** *(cfu/ m³)*	***Aspergillus fumigatus*** **40°C** *(cfu/ m³)*	***Thermophilic Actinomycetes*** **55°C** *(cfu/ m³)*
1	Waste reception and shredding hall, near fire escape	1.73×10^5	2.77×10^4	8.56×10^3	1.75×10^5	2.55×10^4
2	Waste reception and shredding hall, right of oversized material	3.46×10^5	8.1×10^4	2.42×10^4	2.12×10^5	7.58×10^4
3	Waste reception and shredding hall, near green bin	2.19×10^5	3.19×10^4	1.50×10^4	1.98×10^5	2.90×10^4
4	Waste reception and shredding hall, left of oversized material	2.15×10^5	1.01×10^5	1.63×10^4	5.57×10^5	3.28×10^4
5	Waste reception and shredding hall, on loading shovel	3.38×10^5	6.61×10^4	1.18×10^5	4.91×10^5	8.84×10^4
6	Waste reception and shredding hall, personal loader driver	2.20×10^4	7.67×10^3	7.85×10^3	1.67×10^5	1.24×10^4
7	Waste reception and shredding hall, personal litter picker	2.16×10^5	6.67×10^4	5.19×10^4	1.53×10^5	3.22×10^4
8	Screen and maturation area, on central plinth	1.08×10^4	1.28×10^5	2.28×10^5	6.95×10^3	1.08×10^6
9	Screen and maturation area, middle of hall	1.67×10^4	1.71×10^5	2.42×10^5	8.27×10^3	1.08×10^6
10	Screen and maturation area, right of screener	1.46×10^4	2.51×10^5	2.30×10^5	7.66×10^3	1.16×10^6
11	Screen and maturation	2.76×10^3	1.66×10^5	1.10×10^5	2.23×10^3	1.21×10^6

	area, left of screener					
12	Screen and maturation area, far side of hall	1.32×10^4	1.17×10^5	2.04×10^5	6.48×10^3	7.74×10^5
13	Screen and maturation area, personal driver	4.12×10^3	7.76×10^4	1.29×10^5	4.31×10^3	4.29×10^5
14	Screen and maturation area, outside of cab	1.71×10^4	1.32×10^5	5.69×10^4	6.43×10^3	9.75×10^5
15	Outside on corner of screener building	1.80×10^3	6.94×10^3	3.59×10^4	ND	1.91×10^4
16	Outside opposite the waste entrance on skip	1.05×10^3	6.7×10^2	2.9×10^2	9.5×10^1	1.9×10^2

Table 10: Fungal and Bacterial Measurements at Indoor Site

The table illustrates the concentrations of fungi and bacteria calculated at the IVC site over a four-hour period. The analysis conducted at the Health and Safety Laboratory in Buxton is reported in a standardised way to include concentrations of environmental fungi and bacteria, as well as pathogenic bacteria cultivated at the relevant temperatures. The final two columns describing concentrations of Aspergillus fumigatus and Actinomycetes spp. are of most interest in this study.

4.3.2. Outdoor Site

The results from the outdoor windrow site are shown below. The data in the tables mirror those from the indoor site in that the first demonstrates total dust concentrations and the second, the airborne bioaerosol concentration. Sampling times ranged from 225-240 minutes.

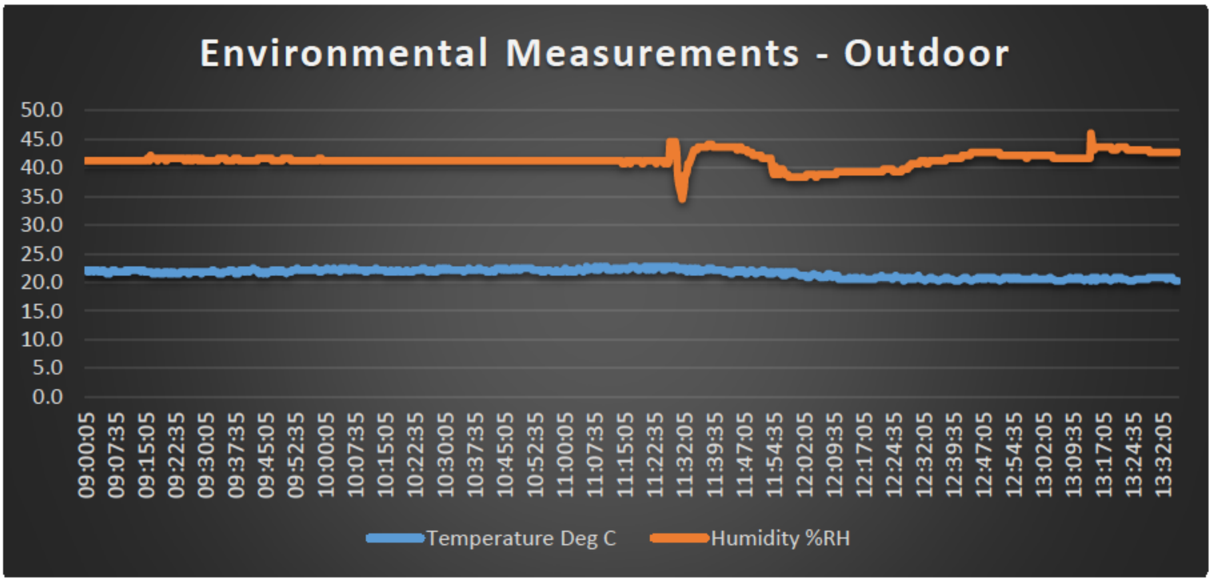


Image 11: Environmental Measurements at Outdoor Site

The graph shows temperature (blue line) and air humidity (orange line) recorded during the study period. Time is displayed along the x-axis with the environmental parameters along the y-axis. On this occasion, there was no change of setting hence the consistency of environmental measurements in contrast to those at the IVC site.

As previously, all flow rates were maintained at 2 litres/minute and checked halfway (2 hours) into the sampling period. Relative humidity remained stable at about 40% for most of the sampling period and similarly air temperature averaged at 21°C. There is a change in humidity levels at about 11.27am which was due to a brief flurry of shredding towards the end of the pile followed by a break in activity in which the main door was opened for a few minutes. Windspeed average was 10km/hour and wind direction maintained at ENE (East-North-East). The airborne concentrations of total dust at the outdoor site were higher than those of the indoor site, with the highest reading measured immediately on the front of the shovel loader. Nonetheless, the time-weighted 8-hour average total dust exposure for the shovel driver was 3.51 mg/m^3 (7.012 x 4/8). Although higher than at the indoor site, this value was below the workplace exposure limit for inhalable dust specified under the Control of Substances Hazardous to Health Regulations 2002.

Filter Number	Sample Details	Total Particulate (mg)	Airborne Concentration (mg/m^3)
1	Shovel load driver	3.226	7.012
2	On the front of the shovel loader	62.433	137.518
3	Corner of the shed to the right of the screeners	0.516	1.108
4	To the far left of the screeners close to windrow approx 30m	0.611	1.365
5	Left opposite screeners 20M	4.001	9.052
6	Facing screener (2) 20M to the left	4.151	9.433
7	Facing screener 20M perpendicular	4.416	10.083
8	Facing screener 20M to right	0.102	0.245
9	Facing screener 50M downwind (to the right)	0.268	0.651
10	Facing screener 50M downwind (to the left)	0.249	0.607
11	Facing screener 50M downwind (perpendicular)	0.266	0.656
12	Behind screener 30M upwind	<0.033	<0.083
13	Behind screener 30M upwind	<0.033	<0.084
14	Behind screener 30M upwind	<0.033	<0.084
15	Weigh bridge control	<0.033	<0.079
16	Facing screener (2) 20M	1.450	4.503

Table 11: Total Dust Measurements at Outdoor Site

The table demonstrates the measurements of total dust obtained from 16 samples placed at the outdoor windrow site over a four-hour period using IOM filter heads. Sample 1 was a personal exposure sample for the cab driver. The downwind samples at 50 metres were taken for a further study in collaboration with the Environment Agency. Once again, total dust samples were converted to airborne concentrations using the formula specified in the methods section.

Airborne concentrations of *Aspergillus fumigatus* ranged from 10^3 at 30 metres upwind to 10^8 at the shovel loader. The corresponding range for *Actinomycetes* was 10^3 to 10^7. Comparisons between the indoor and outdoor site are limited by the fact that bioaerosol emissions from only one composting process (screening) was assessed at the outdoor site, whereas emissions from two processes (shredding and screening) were recorded at the indoor site. Nonetheless, *Thermophilic Actinomycetes* emissions from screening activities at the indoor site were in the order of 1-2 log higher than the outdoor site (10^6 as opposed 10^5), whereas the reverse was seen for *Aspergillus fumigatus*.

Filter Number	***Sample Details***	**Environmental Fungi 25°C *(cfu/ m³)***	**Environmental Bacteria 25°C *(cfu/ m³)***	**Potential Pathogens 37°C *(cfu/ m³)***	***Aspergillus fumigatus* 40°C *(cfu/ m³)***	***Thermophilic Actinomycetes* 55°C *(cfu/ m³)***
1	Shovel load driver	2.17×10^3	8.70×10^2	4.05×10^4	1.04×10^4	2.22×10^5
2	On the front of the shovel loader	1.02×10^4	4.41×10^3	7.27×10^7	1.30×10^8	1.22×10^7
3	Corner of the shed to the right of the screeners	4.29×10^2	2.15×10^3	2.66×10^5	6.33×10^5	2.69×10^4
4	To the far left of the screeners close to windrow approx 30m	2.68×10^3	1.45×10^3	1.89×10^4	6.25×10^4	2.05×10^5
5	Left opposite screeners 20M	1.36×10^3	7.92×10^2	5.44×10^5	1.72×10^6	4.58×10^5
6	Facing screener (2) 20M to the left	1.02×10^3	ND	1.36×10^5	2.48×10^4	2.20×10^5

7	Facing screener 20M perpendicular	1.83×10^3	6.85×10^2	2.15×10^6	1.03×10^6	1.40×10^5
8	Facing screener 20M to right	6.01×10^2	ND	3.13×10^3	6.61×10^3	2.68×10^4
9	Facing screener 50M downwind to the right (20M from the screened windrow)	1.21×10^2	ND	8.13×10^4	2.11×10^4	1.71×10^4
10	Facing screener 50M downwind to the right (20M from the screened windrow)	1.46×10^3	ND	1.57×10^4	8.78×10^3	3.32×10^4
11	Facing screener 50M downwind (20M from the screened windrow)	4.93×10^2	ND	8.25×10^3	9.73×10^3	2.34×10^4
12	Behind screener 30M upwind	5.05×10^2	ND	3.79×10^2	1.14×10^3	5.05×10^2
13	Behind screener 30M upwind	1.27×10^3	ND	1.90×10^3	4.70×10^3	4.19×10^3
14	Behind screener 30M upwind	1.40×10^3	ND	2.17×10^3	4.21×10^3	4.59×10^3
15	Weigh bridge control	7.21×10^2	1.56×10^3	1.01×10^4	1.01×10^4	7.81×10^3
16	Facing screener (2) 20M	1.55×10^3	2.17×10^3	5.32×10^4	3.84×10^4	2.81×10^5

ND=Not Detected

Table 12: Fungal and Bacterial Measurements at Outdoor Site

The table illustrates the concentrations of fungi and bacteria calculated at the outdoor site over a four-hour period. Once again, results are reported in a standardised way as with those from the IVC site. The final two columns describing concentrations of Aspergillus fumigatus and Actinomycetes spp. are of most interest in this study. Their relevance to health, and comparability with previous studies is discussed below.

4.4. Discussion

In this study, I examined bioaerosol emissions generated from industrial composting activities at one indoor and one outdoor site using conventional sampling and enumeration methods. At the indoor site, airborne concentrations of *Aspergillus fumigatus* were higher during the shredding than the screening process, in the order of 1-2 log magnitude. The opposite pattern was seen for *Actinomycetes spp*. With respect to screening activity alone, higher concentrations of *Aspergillus fumigatus* were found at the outdoor windrow site, but with higher concentrations of *Actinomycetes spp.* at the indoor site.

To interpret this finding, it is prudent to re-refer to the scientific processes involved in composting. Shredding is followed by a thermophilic maturation phase during which compost piles are turned, after which the material is screened. Thus, one would assume that higher concentrations of thermophilic organisms would be emitted from screening than shredding, but why this is only the case for *Actinomycetes* in this study and not *Aspergillus fumigatus* is uncertain. One possibility is that screening temperatures are sufficiently high such that a greater proportion of *Aspergillus* fungi are destroyed as compared to thermophilic bacteria. Additionally, the higher energy screening process may destroy or aerosolise viable fungal organisms differentially to bacterial species. This issue may merit further study since it may have practical implications for the industry. Although workers may be involved in all stages of composting, understanding which bioaerosols are more likely to be liberated at different points of the process may improve assessments and judgments about fitness and safety for work. For example, a worker reporting respiratory symptoms when screening and sensitised to *Actinomycetes* by blood maybe restricted from this activity but remain involved in other areas of the process such as sorting green waste deliveries or bagging compost for sale. Such modifications to an individual's work pattern could enable them to remain in employment. Nonetheless, as sensitisation may occur at low exposure concentrations and compost workers often need to be multi-skilled, such recommendations may be difficult to accommodate at smaller sites.

Recorded emissions at both sites are consistent with those noted previously in the literature, with levels of bioaerosol lying within the expected range. In the most recent and detailed systematic review of occupational exposures at green waste facilities, *Aspergillus fumigatus* concentrations in air ranged from 10^1 to 10^6 cfu/ m^3 (Pearson et al 2015). In this study, most values in the indoor site fell between 10^3 - 10^5 cfu/ m^3 and 10^3 - 10^6 cfu/ m^3 at the outdoor site. The only outlier was a value of 10^8 at the front of the shovel loader at the outdoor site, but it is probably unlikely that any workers would be exposed at these levels except for the cab driver in the absence of effective controls. An exception to this could be a worker who enters the area immediately after agitation activities had taken place without adequate respiratory protection, or similarly if a driver opens their cab door or windows and remains in the area at that time. Workers' RPE behaviours were not assessed in detail in this study and thus informed commentary is difficult. *Thermophilic Actinomycetes* concentrations have ranged from 1 to 10^6 cfu/ m^3 in previous studies and my findings here are similar. To this end, there was little reason to believe that the bioaerosol emissions from the two sites studied here were in any way atypical of the industry. This reinforced their appropriateness as locations at which to study the health complaints of workers.

The IOM sampling head used in these exposure studies did not allow for the differentiation of inhalable and respirable dust components. Such a differentiation could have provided additional value in interpreting the data, since the elevated levels of dust seen at the outdoor site on the shovel loader and within 20 metres of the compost pile during turning activities may pose a health risk to individuals working in that environment, particularly if workers enter the area immediately after the activity. It is indeed possible that such individuals may be exposed to elevated levels of inhalable and respirable dust in such instances, but this would require further study. One practical outcome from such a study could be the implementation of restrictions on work activities within a certain distance of the compost pile for a certain period until dust levels have settled to below the relevant occupational exposure limits, particularly if controls to exposure may be insufficient. Longitudinal and continuous dust measurements would be needed to inform this, such as those provided by newer particle counters which use infra-red technology to measure particle counts as a function of particle size. A similar principle could be applied to other compost agitation activities such as shredding and screening where concerns about elevated dust exposures exist following such activity.

4.4.1. Strengths and Limitations

This study has several strengths. Firstly, when we conducted the data collection, we were reassured by both site managers that no new or different controls to exposure, practices or behaviours were introduced because of our presence. Thus, the findings are likely to be representative of normal practice and of mutual benefit, such that results were fed back to management for internal quality assurance purposes. In the case of the outdoor site, samples were collected in weather conditions consistent with the UK summer norm, but a single sampling period is unlikely to accurately capture the true range of bioaerosol concentrations generated within the studied composting facility, and thus longitudinal assessments would be preferable. For example, summer temperatures may rise above 30^{o} Celsius, and a period of rain preceding data collection may reduce bioaerosol emissions and thus measured concentrations.

The sites studied here were owned by the two largest companies taking part in the project which both adhered to similar working practices and safety standards. This bioaerosol data provided a useful context in which to evaluate findings from the health component of the project as the bioaerosol emissions were within the typical range reported in the literature. Finally, as described above, my data provides some insight into the different types of bioaerosols generated at different stages of the composting process. I believe this issue merits further investigation since there may be practical implications for the industry in informing the occupational management of workers.

There are also some limitations. I was unable to differentiate between dust particle sizes which would have enabled me to calculate inhalable and respirable fractions. Nonetheless, the low levels of total dust captured at both sites were reassuring, and below the relevant occupational exposure limits. IOM filters are known to be sensitive to environmental conditions and thus the higher relative humidity of the maturation hall in the indoor site may have affected the quality of data captured. Additionally, there is a possibility that some filters may have been overloaded, particularly in the dustier outdoor settings, leading to an underestimation of dust and bioaerosol counts.

Overlap of organisms across different growth temperatures is a known problem using this culture method. Although techniques to identify specific organisms exist, I was unable to access these at the HSL. Established techniques include the use of matrix-assisted laser desorption ionization–time of flight mass spectrometry (MALDI-TOF) in conjunction with nucleic acid sequencing and amplification. This approach has been used, for example, to identify bacterial and fungal genera capable of inducing ODTS (Madsen et al 2015). Accordingly, I was unable to identify specific bacterial species because the overlap of organisms growing at 25 and 37^{o}C precluded this. Endotoxin, β-glucan, and mycotoxin were not measured because of funding limitations and these would have provided further information as to the types of exposures encountered by workers. Such data could also inform the interpretation of reported symptoms and their attribution to work activities. This might include complaints of rhino-conjunctivitis or lower airways complaints. Opportunities for further work in this area are covered in the discussion chapter of this thesis.

Chapter 5: Cross-Sectional Health Study

5.1. Introduction

The following section describes the findings from the cross-sectional study of the health of UK compost workers. My overarching hypothesis was that there is a high prevalence of sensitisation to *Aspergillus fumigatus* amongst UK compost workers, with a corresponding significant burden of allergic illness. Accordingly, the main research questions of this study are listed below:

- What is the prevalence of sensitisation to bioaerosols in compost including *Aspergillus fumigatus, Cladosporium herbarum, Alternaria alternata and Thermophilic Actinomycetes* in the UK industrial composting workforce?
- What is the association between sensitisation status to *Aspergillus fumigatus* and work-related symptoms?
- What is the association between sensitisation status to aeroallergens tested in this study (poly, mono and non-sensitised) and symptoms?
- What is the concordance between SPTs and IgE blood tests used to detect sensitisation in workers to bioaerosols in compost?

Although not primary research questions, the study afforded the opportunity to collect data pertaining to several issues described in the introduction chapter. Accordingly, data comparing the prevalence of symptoms and sensitisation according to years worked in the industry, site type and asthma status will also examined. Finally, I shall provide a narrative regarding my observations of the use of RPE and health surveillance practices.

5.2. Methods

5.2.1 Questionnaire Development

I developed a health questionnaire to identify the prevalence and nature of work-related health complaints amongst compost workers. Most items were drawn from a respiratory health questionnaire developed by the HSE for other occupational groups. Nonetheless, some items were added following review to capture symptoms more specific to conditions such as EAA, ODTS and ABPA. An example is that of the question "Do you ever cough up green strings or brown plugs" as an indicator for ABPA. Other additions included specific items about the presence of fever, malaise, musculoskeletal aches, shivering, weight loss and flu-like symptoms which could suggest EAA or ODTS.

Section A of the questionnaire captured workers' demographics including age, height, weight, ethnicity and smoking status. Section B covered workers' jobs including their proximity to compost, time spent in their current post, and occupational history to assess past bioaerosol exposure. Section C assessed workers' self-reported use of respiratory protective equipment (RPE), including the types worn and for which tasks. Where workers did not wear RPE, the reasons for this were recorded. Section D enquired about symptoms suggestive of rhinitis and conjunctivitis such as eye, nose and throat irritation; as well as lower airways involvement through cough, sputum production, chest tightness, shortness of breath and wheeze. A set of questions asking about a history or presence of work-related rash was also included. Items enquiring about gastro-intestinal symptoms were excluded due to concerns about their low specificity for bioaerosol exposures, with evidence suggesting that other exposures such as *Legionella spp*. may be responsible for such symptoms (Bonifait et al 2017). Questions were also asked about underlying health conditions which may increase the workers' susceptibility to bioaerosol-related illness such as asthma, COPD, cystic fibrosis and immunosuppression from medication or underlying disease. A history and family history of eczema, asthma and hay fever was also elicited.

I conducted a protocol analysis with three medical colleagues at the Centre for Workplace Health in the Health and Safety Laboratory, Buxton and six lay colleagues at the University of Sheffield who reviewed the questionnaire for content, accuracy and ease of completion. Furthermore, an industry specialist (Organics Technical Manager) who at the time of the study was working for a composting company not involved in the study, agreed to review the questionnaire for its suitability for the workforce.

5.2.2. Project Administration

Project information was sent to all interested companies by e-mail. I subsequently met with safety managers to clarify any concerns about the project and discuss the logistics of conducting the study on-site. This included finding an appropriately sized and private room to see volunteer workers, locating adequate washing facilities and identifying dates in which most workers would be on-site. Workers received information about the project prior to data collection and were asked if they wished to take part in the study. Each worker was invited to meet me at staged intervals to minimise disruption to work process. Each consultation lasted approximately 15-20 minutes. The format of the consultations was as follows:

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I discussed the purpose of the project with the worker and its intended outcomes. These outcomes included information regarding their own health as well as data for management to inform risk assessment and health surveillance where relevant. I discussed possible complications of the SPT and blood tests such as local irritation and bruising. The worker was afforded the opportunity to ask questions about how the project was developed, to be conducted or data to be handled and communicated. Subsequently, the worker was asked to provide written consent for each stage of the study to include completing the questionnaire and receiving the SPT and blood tests.

Data Collection

I conducted the SPT following relevant safety checks including a history of severe reactions to the allergens involved and assessment of pertinent medical history such as a history of severe asthma and use of medications such as beta-blockers and angiotensin-converting enzyme inhibitors which may dampen responses to emergency intramuscular adrenaline in the event of anaphylaxis. I also clarified whether the worker had recently taken any medication which could interfere with the SPT such as antihistamines. A standard European panel of allergens was used (Alk-Abello A/S, Horsholm Denmark - Manufacturer). Workers were also skin prick tested to the three-common fungal moulds within UK compost - *Aspergillus fumigatus; Cladosporium herbarum and Alternaria alternata.* Workers were also tested to 3-tree, 6-grasses mix (smooth meadow grass/*Poa pratensis*; cock's foot grass/*Dactilis glomerata*; perennial rye grass/*Lolium perenne*; timothy grass/*Phleum pratense*; meadow fescue/*Festuca pratensis*; meadow oat grass/*Helictotrichon pretense*) and house dust mite antigen *Dermatophagoides pteronyssinus*. Cat and dog allergens were not tested due to funding constraints. Workers were also tested to positive (histamine) and negative controls.

I performed the SPT in a standardised fashion (Heinzerling et al 2009). Half a millilitre of fungal antigen in liquid form using a plastic pipette taken from a small glass bottle was placed onto the volar aspect of the participant's forearm, following which a 1mm calibrated lancet was used to 'prick' the surface of the skin for at least one second without causing bleeding. For each allergen, a new lancet (ALK-Abello, Manufacturer) was used to reduce cross-contamination. Excess solution was carefully blotted with a tissue. A gap of at least 2 cm was left between each droplet, once again to prevent cross-contamination. For each SPT, I noted whether a skin reaction (in the form of a wheal) was visible. If so, I calculated the mean wheal diameter as (largest longitudinal diameter + longest transverse diameter / 2). This was measured fifteen minutes post-administration as is standard practice (Bousquet et al 2007; Van Kampen et al 2014). A test was regarded as positive if the value was ≥3 mm in conjunction with a positive histamine control and a negative diluent control. Whilst the SPT was waiting to be read, I completed the health questionnaire with the worker. This format enabled me to clarify answers with the worker whilst on-site. Following this, I took a 5 ml sample of venous blood from the antecubital fossa of each consenting worker using a standardised venepuncture technique. A second 5ml blood sample was taken with the patient's consent in case of accidental damage to or loss of the samples or data. Blood samples were left to coagulate either for 3-6 hours at room temperature or overnight at 4° C at the Health and Safety Laboratory, Buxton. The blood was centrifuged by a laboratory technician the following morning at 2500 to 3000 rpm for 10 to 15 minutes; the serum was removed with a pipette and transferred to 2 ml polypropylene microtubes with screw tops (Sarstedt, Nfimbrecht, Germany). Aliquots were stored in a freezer at -20° C. I transported the aliquots from the Health and Safety Laboratory in Buxton to the Northern General Hospital, Sheffield on the day of analysis. Blood samples were analysed at the Immunology Laboratory at the Northern General Hospital, Sheffield and assessed for the presence of *in vitro* sensitisation to the fungal moulds *Aspergillus fumigatus*, *Cladosporium herbarum and Alternaria alternata* and the thermophilic bacterial antigen *Actinomycetes spp*. Specific IgE and IgG measurements (ImmunoCAP) blood concentrations were measured for the fungal moulds and *Actinomycetes spp.* All assays for specific IgE were judged to be positive at values of 0.35 kU/L or greater (Bunger et al 2007). Standard laboratory reference values were used for specific IgG measurements. Blood tests for IgE sensitisation to environmental aeroallergens were not performed due to financial constraints.

Data Analysis

Data were analyzed using Microsoft Excel and SPSS for Windows Version 23.0. The companies were treated as a single dataset since all were relatively large industrial employers and might be reasonably expected to have the resources to adhere to higher health and safety standards than smaller operations, as has been shown in the construction industry (Mills & Lin 2004). This difference could be notable in sites with less than 5 workers, in which case there is no legal requirement in Great Britain to have a written health and safety policy. Descriptive prevalence statistics were obtained for demographic and occupational characteristics including age, gender, smoking status and years working in the industry. Similarly, prevalence data were calculated for sensitisation to fungi and bacteria in compost, as well as common environmental aeroallergens.

5.3. Case Definitions and Criteria

This section outlines the key definitions used in this study. Their utility and appropriateness will be described in the discussion chapter. Where available standard and established definitions have been applied but in the absence of existing data or literature upon which to base them, some definitions are arbitrary.

Job Role

From discussions with management, it became clear that most workers performed a few different composting activities during their day. This could include working in a vehicle to turn or shred compost, manually sorting waste or picking litter. Furthermore, some individuals had both office-based and field responsibilities such as site managers and compost quality samplers. Following discussion with the Organics Technical Manager at one company not participating in the study about the complexities of creating accurate job descriptions for participants; it was suggested that “high”, “medium” and “low” exposure categories were created for onsite operatives, mixed site and office duties and office duties only respectively.

Weighbridge workers however were classified as follows. In instances where weighbridges were located within 250 metres of composting activities, workers were placed in the high category, whereas they were placed in the low category if based outside of this distance. This is because the weighbridge is the first ‘port of call’ for external visitors to the site, and thus weighbridge windows and doors may be open for large parts of the working day, particularly during high activity periods. It could not be assumed therefore that working in the weighbridge office would afford significant additional protection from bioaerosol exposure during composting activities as might be the case for office workers on site.

Mono/Polysensitisation

A worker was classified as 'monosensitised' if they had a positive skin prick test or specific IgE to only one allergen, whereas they were considered 'polysensitised' for 2 or more positive reactions to the panel tested in this study (Migueres et al 2014). Previous work has suggested that this is a more useful distinction in explaining variability in respiratory symptoms, such as bronchial hyper-reactivity complaints, than stratification by atopic status (Chinn et al 1999).

Irritant Symptoms

Irritant symptoms were defined as the presence of rhinitis, conjunctivitis or lower airways symptoms such as cough, wheeze or shortness of breath in the absence of sensitisation by skin or blood to the allergens tested in the study.

Respiratory Protective Equipment (RPE)

This included all personal forms of RPE ranging from those with low protection factors such as simple cloth face masks and disposable half-mask respirators, to full-face respirators and air-fed helmets offering a higher level of protection. Workers were asked a separate question as to whether they were based in a cab during their work but for data analysis, filtered cabs with or without positive pressure were considered a form of RPE. The rationale for this being that cab filters are designed to reduce workers' exposure to bioaerosols. Tractors or other vehicles without filters were not considered a form of RPE.

Immunosuppression

This encompassed all individuals suffering from primary immunosuppression due to underlying medical disease, or those who may be immunosuppressed due to effects of medical treatment or previous therapy. The latter included those who may be taking cytotoxic medication, disease-modifying drugs such as biological agents, or patients who have had an organ transplant.

Work-Related Symptoms

In keeping with the British Occupational Health Research Foundation's guidance, the subject's symptoms were considered as "work-related" if there was an association between them and work (Kazer 2010). Specifically, at least one of them needed to occur at or be exacerbated by work, or up to a few hours after work, and would need to improve or disappear when away from work, such as on days-off or holiday periods. Assessed symptoms were those of eye, nose and throat irritation as well as cough, chest tightness, wheeze and dyspnoea.

Diagnosis of Illness

The purpose of this study was to identify symptoms and the prevalence of sensitisation to bioaerosol in the workforce and did not extend to the diagnosis of clinical conditions. Nonetheless, in any cases where there was clinical concern that reported symptoms and clinical findings may be suggestive of EAA, ODTS, ABPA or obstructive lung disease such as OA or COPD, this was communicated to the participant's GP and/or specialist. An example for EAA was the report of attacks of cough, wheeze or shortness of breath in the presence of systemic symptoms and sensitisation to bioaerosol.

5.4. Statistical Analysis

A logistic regression analysis was conducted to assess the association between sensitisation and symptoms. Workers were considered sensitised to *Aspergillus fumigatus* if they had a positive skin prick test and/or specific IgE in accordance with standard definitions (Migueres et al 2014). Specific IgE results were not available for 5 individuals. For these cases, sensitisation status was elicited from SPT recordings alone. 25 workers were sensitised to *Aspergillus fumigatus* in total (21 by SPT alone, 1 by specific IgE only, 3 both). The outcome variables were grouped such that eye and nose irritation were considered collectively as mucous membrane irritation (MMI) and cough, wheeze, chest tightness and shortness of breath were grouped into lower airways symptoms.

Age, gender, smoking status, *Aspergillus* sensitisation, job role, years in service and site type were included as co-variates in the analysis. Smokers that had quit in the last 12 months were considered current smokers. In SPSS, gender was categorised as (0=female, 1=male); smoking status (0=no, 1=yes); length of service (0 = less than 5 years, 1= between 5 and 10 years, 2= more than 10 years); aspergillus sensitisation (0=no, 1=yes); site type (0=indoor, 1=outdoor); and sensitisation status (0=none, 1= monosensitised, 2=polysensitised). Asthma was similarly dichotomised (0=no, 1=yes).

Following discussion with the Organics Technical Manager about appropriate classifications, job roles and proxy exposure status were categorised as “high” for an on-site operative or those workers that spent more than 50% of their working time performing on-site tasks such as sampling. Other workers, such as those predominantly office-based were categorised as low exposure.

5.5. Results

5.5.1. Demographic and Health Characteristics

111 of 125 invited compost workers took part in the study across six UK industrial composting companies; a response rate of 88.8%. Most participants were male (n=102; 91.8%), with the nine female participants all working in offices or weighbridges. All workers were of white Caucasian origin, with only three not of British nationality. The average BMI was 29, which is a value in the 'overweight' category. 45 individuals were in the 'obese' category recording BMIs of 30 or greater. Approximately $2/3^{rds}$ of participants reported to have never smoked. Nine workers stated that they had previously been diagnosed by a doctor as having or currently being treated for asthma. Twenty participants reported suffering from eczema (5 workers), hay fever (13 workers) or both (2 workers). One individual stated they had all three conditions. Three workers were taking immunosuppressant tablets to include mycophenylate mofetil and methotrexate for arthritic conditions and another taking tacrolimus following a renal transplant. One individual had undergone a splenectomy following a road traffic accident thirty years' previously.

Demographic Characteristics	**Mean (minimum-maximum)**
Age (years)	44 (18-69)
Height (cm)	177 (157-193)
Weight (kg)	90 (53-140)
Body Mass Index (kg/m^2)	29 (19-46)
[redacted]	

Health Characteristics	N (%)
Never/Ex-Smoker	75 (67.6)
Current Smoker	36 (32.4)
Self-Reported History of Doctor-Diagnosed Asthma	9 (8.1)
Self-Reported History of Eczema/Hay Fever	20 (18.1)
Self-Reported History of Any Allergy	13 (11.7)
Doctor-Diagnosed COPD/Chronic Bronchitis/ Emphysema	1 (0.01)
Immunosuppression	4 (3.6)

Table 13: Demographic and Health characteristics of study participants

5.5.2. Occupational Characteristics

Most participants (72%) were based on open windrow sites. Seventy-five participants (68%) worked as compost operatives which included tasks such as litter picking in the vicinity of the compost piles; sorting waste, shredding, turning and screening of compost. Twenty-eight had combined duties to include management activities, administrative work and operational duties such as driving cabs and manually sampling compost to check that it met appropriate quality standards. Eight individuals were solely office-based. Workers in the weighbridges were classified as exposed to bioaerosols if these buildings were within 250 metres of the compost piles for reasons described earlier.

About one-half of participants reported using personal RPE during their work for one or more activities. A more detailed discussion of this will follow. Most workers had been in their current job for between 1 and 5 years, but over one-third had been in their job more than 5 years, with not an insignificant number (14 individuals) having worked for more than 10 years in their job. Just over one-quarter of participants had previously worked in the waste and recycling industry before their current job, with just under one-fifth having worked in another industry in which bioaerosol exposure is a known hazard. Most of these individuals (16 out of 20 participants) had worked as farmers, and all 16 reported living on a farm during their childhood.

Occupational Characteristics	**N (%)**
Windrow Site	80 (72.1)
In-Vessel Composting Site	31 (27.9)
On site Operative (predominant role)	75 (67.6)
Combined Duties	36 (32.4)

Workers who use a filtered cab	59 (53.2)
Used any form of RPE during course of work	56 (50.5)
Less than 5 years in current job	39 (35.1)
>5 years and < 10 years in current job	30 (27.0)
>10 years in current job	42 (37.8)
Previously worked in waste industry before current employer	30 (27.0)
Previously worked in another industry with bioaerosol exposure*	20 (18.0)

Table 14: Occupational Characteristics of Participants

**Assessed according to occupational list provided by Swan et al 2003*

5.6. Prevalence of Sensitisation

5.6.1. Skin Prick Tests

All 111 participants consented to the SPT procedure, with all but 4 of these also agreeing to have a blood sample taken. One blood sample was too lipaemic to analyse, resulting in 106 viable results.

Allergen	Crude Sensitisation Rate N (%)
SPT *Aspergillus spp.*	24 (21.6)
SPT Cladosporium spp	13 (11.7)
SPT Alternaria spp.	12 (10.8)
SPT House Dust Mite	21(18.9)
SPT 3-Tree	13 (11.7)
SPT 6-Grasses	27 (24.3)

Table 15: Sensitisation by SPT to bioaerosol components

Formal comparisons using standardisation techniques with other studies were not possible. For instance, in the European Community Respiratory Health Survey I (ECRHS I), 1398 valid SPTs were conducted across four English testing centres, as part of a larger study across 35 centres in 15 countries. Age-sex standardised sensitisation of 3.5% and 7.3% were reported for *Cladosporium. spp*. and *Alternaria spp.* respectively, with 29.1% for house dust mite and 21.8% for grass pollen. Nonetheless, I was unable to obtain the underlying age/sex structure or smoking status for the sampled ECRHS participants to compare to this study (Bousquet et al 2007). Similar limitations are notable for data from the GAL^2EN skin test study which had reported the prevalence of sensitisation to common allergens in individuals attending specialist allergy centres across Europe (Heinzerling et al 2009). The authors produced age and sex-standardised sensitisation data for 11 of the 14 countries except for Greece, Switzerland and the UK which were presented as crude rates. Information was captured for indoor and outdoor allergens such as *Aspergillus spp., Cladosporium spp*. and *Alternaria spp*. as well as common aeroallergens such as grass pollen, tree pollen and house dust mite antigen. Crude sensitisation rates for UK participants were 7.9%, 7.1%, 39.7% and 54% for *Aspergillus spp., Cladosporium spp*., house dust mite and grass pollen respectively. Although it was determined 127 individuals participated, once again the age/sex structure was not available. In addition, given that participants were all patients referred to specialist Immunology centres, these figures may not be representative of the UK general population as the individuals studied may have had an elevated predisposition to allergic illness.

5.6.2. Specific IgE and IgG

No individuals were sensitised to *Actinomycetes spp.* components by specific IgE. Eight (7.5%), 1 (0.01%) and 4 individuals (3.7%) were sensitised by IgE to *Aspergillus spp., Cladosporium spp. and Alternaria spp.* respectively. Approximately 1/4 of participants in this study were IgG positive to *Aspergillus fumigatus*. 10 out of 27 (37%) of these individuals were working in jobs which were not expected to encounter the highest exposures on-site, such as office-based work or in the weighbridge. Of note, all weighbridges were further than 250 metres away from the compost piles on all but two sites. Although 50 workers had clinically detectable levels (>2 mg/L) of IgG to *Saccharopolyspora rectivirgula*, none had a value greater than 59.9, the threshold used in this study for a clinically significant value.

Antigen	Crude Sensitisation Rate N (%)
Aspergillus IgE	8 (7.5)
Cladosporium IgE	1 (0.9)
Alternaria IgE	3 (2.8)
Aspergillus IgG *	22 (20.8)
*S.rectivirgula IgG***	0 (0)
*T.vulgaris IgG***	0 (0)

Table 16: IgE and IgG sensitisation in compost workers to moulds and bacteria

*(*Normal range 0-39.9 and** Normal range 0-59.9)*

5.6.3. Regression Analyses: Work-related symptoms

The results of the logistic regression examining the association between mucous membrane irritation and predictor variables are shown below. The numbers in parenthesis refer to analysis between subgroups. (1) represents the analysis between the lowest and highest groups of the variable. For instance, this corresponds to the prevalence of MMI between those workers in the industry less than 5 years and greater than 10 years for the 'length of time' variable. (2) represents the findings from the analysis between the middle and highest groups, that is 5-10 years in the industry and greater than 10 years working in the industry.

Covariate	Beta	p-value	Exp(B)	95% CI Lower	95% CI Upper
Age	-0.023	0.222	0.978	0.943	1.014
Smoking (1)	0.035	0.940	1.036	0.416	2.578
Gender (1)	-1.658	0.241	0.190	0.012	3.043
Site (1)	-0.404	0.432	0.668	0.244	1.826
Aspergillus (1)	0.399	0.573	1.491	0.372	5.974
Length of Time		0.317			
Length of Time (1)	-0.811	0.150	0.444	0.147	1.341
Length of Time (2)	-0.591	0.284	0.554	0.187	1.634
Job Role (1)	-0.203	0.685	0.816	0.306	2.177
Sensitisation		0.136			
Sensitisation (1)	-0.877	0.157	0.416	0.123	1.402
Sensitisation (2)	-1.397	0.099	0.247	0.058	1.057

Table 17: Regression Analysis: Predictor Variables for Mucous Membrane Irritation

The results indicate that none of the variables in the model were significant predictors for the presence of mucous membrane irritation amongst the surveyed workforce. Furthermore, differences in length of time working in the industry, job role and sensitisation status to the aeroallergens tested in this study did not significant predict the reported prevalence of MMI across the respective subgroups. Due to the clinical importance of the onset of eye and nasal irritation in developing irritant and potentially allergic illness related to bioaerosol exposure, separate analyses were performed for these outcome variables using the same predictor variables as above. The results for the prevalence of eye and nasal symptoms are shown below:

Covariate	Beta	p-value	Exp(B)	95% CI Lower	95% CI Upper
Age	0.013	0.798	1.006	0.961	1.053
Smoking (1)	-0.330	0.717	0.810	0.259	2.533
Gender (1)	-2.025	0.298	0.174	0.006	4.693
Site (1)	0.169	0.892	1.089	0.319	3.714
Aspergillus (1)	-1.132	0.172	0.323	0.064	1.634
Length of Time		0.089			
Length of Time (1)	-1.618	0.039	0.218	0.051	0.929
Length of Time (2)	-0.865	0.183	0.426	0.122	1.494
Job Role (1)	0.649	0.261	1.914	0.617	5.933
Sensitisation		0.171			
Sensitisation (1)	-0.599	0.916	1.086	0.237	4.977
Sensitisation (2)	-1.847	0.084	0.182	0.026	1.255

Table 18: Regression Analysis: Predictor Variables for Eye Symptoms

Once again, none of the variables in the model were significant predictors for the presence of eye symptoms. Nonetheless, stratification of the results indicated there were significant differences in reported eye symptoms between those that had been working less than 5 years and more than 10 years in the industry. The corresponding B coefficient suggests that the prevalence of eye symptoms is higher in those having worked for more than 10 years in the industry. A Fisher's Exact Test was conducted to assess the association between Aspergillus sensitisation and eye symptoms in those working in the industry for more than 10 years (n=42). No significant difference was found at the 95% confidence level (Fisher's Test = 0.490). There were no statistically significant relationships between the predictor variables and the overall prevalence of nasal symptoms, nor were there significant differences in nasal symptoms following stratification according to length of time in the industry, job role, or overall sensitisation status. The relationships with lower airways symptoms reported by 9 workers were also examined with similarly non-significant findings. These results are shown in the tables below.

Covariate	Beta	p-value	Exp(B)	95% CI Lower	95% CI Upper
Age	-0.025	0.237	0.976	0.937	1.016
Smoking (1)	0.607	0.267	1.835	0.628	5.363
Gender (1)	-0.275	0.852	0.759	0.042	13.579
Site (1)	-0.554	0.348	0.575	0.181	1.827
Aspergillus (1)	0.974	0.242	2.648	0.518	13.533
Length of Time		0.455			
Length of Time (1)	-0.814	0.214	0.443	0.123	1.600
Length of Time (2)	-0.258	0.672	0.773	0.234	2.552
Job Role (1)	-0.292	0.615	0.747	0.239	2.329
Sensitisation		0.217			
Sensitisation (1)	-0.888	0.189	0.411	0.109	1.547
Sensitisation (2)	-1.419	0.114	0.242	0.042	1.408

Table 19: Regression Analysis: Predictor Variables for Nasal Symptoms

Covariate	Beta	p-value	Exp(B)	95% CI Lower	95% CI Upper
Age	-0.023	0.465	0.977	0.919	1.039
Smoking (1)	-0.954	0.197	0.385	0.090	1.644
Gender (1)	-15.411	0.999	0.000	0.000	0.000
Site (1)	-0.975	0.380	0.377	0.043	3.326
Aspergillus (1)	-0.603	0.600	0.547	0.057	5.214
Length of Time		0.875			
Length of Time (1)	-0.312	0.729	0.732	0.125	4.272
Length of Time (2)	-0.489	0.619	0.613	0.089	4.212
Job Role	-1.255	0.267	0.285	0.031	2.617
Sensitisation		0.961			
Sensitisation (1)	-0.060	0.957	0.941	0.107	8.297
Sensitisation (2)	-0.352	0.785	0.703	0.056	8.821

Table 20: Regression Analysis: Predictor Variables for Lower Airways Symptoms

5.6.4. Relationship between SPT and specific IgE

A higher number of participants were sensitised by skin than by blood. 2x2 tables were constructed to assess the concordance between SPT and specific IgE results for the 106 individuals that agreed to have both tests. Each fungal antigen has been examined separately.

Aspergillus spp.	Positive Blood IgE	Negative Blood IgE	**Total**
Positive SPT	*5*	*18*	*23*
Negative SPT	*3*	*78*	*81*
Total	*8*	*98*	*106*

Cladosporium spp.	Positive Blood IgE	Negative Blood IgE	**Total**
Positive SPT	*1*	*12*	*13*
Negative SPT	0	*93*	*93*
Total	*1*	*105*	*106*

Alternaria spp.	Positive Blood IgE	Negative Blood IgE	**Total**
Positive SPT	*1*	*11*	*12*
Negative SPT	0	*94*	*94*
Total	*1*	*105*	*106*

Table 21, 22 and 23: 2x2 tables of results for SPT and blood test results for fungal allergens

Cohen's Kappa (κ) was calculated to assess concordance. Agreement between the two tests was fair for the fungus *Aspergillus fumigatus,* but poor for and *Alternaria alternata* and *Cladosporium herbarum*. As a commercial SPT does not exist for *Actinomycetes spp*. no such comparison could be performed for bacterial components. The implications of these findings are discussed in chapter 5 of this thesis.

Allergen	**Kappa Statistic κ**
Aspergillus fumigatus	0.24
Cladosporium herbarum	0.13
Alternaria alternata	0.14

Table 24: Kappa Statistics for SPT and Blood Tests for fungal allergens

The table shows fair (Aspergillus) to poor (Cladosporium and Alternaria) concordance between SPT and specific IgE results.

5.7. Asthmatics and Immunosuppressed workers

Of the 9 individuals that reported a doctor-diagnosed history of asthma, 7 stated that their symptoms were well-controlled with beta-agonist and/or steroid inhaler medication. Two individuals reported having experienced at least one episode of chest tightness and shortness of breath in the previous 12 months, with four participants citing at least one episode of wheeze during the same period but none reporting cough. One individual had required an emergency department attendance but not hospital admission. None of the participants stated that their symptoms were worse at work. The prevalence of sensitisation by IgE (skin prick and/or blood) to *Aspergillus fumigatus* and asthma status was examined using a Chi-Squared Test, with the null hypothesis that there was no relationship between the two variables. A 2x2 contingency table was created as below:

Variable	Aspergillus Sensitised	Not Aspergillus Sensitised	**Total**
Asthmatic	*5*	*4*	*9*
Not Asthmatic	*20*	*82*	*102*
Total	*25*	*86*	*111*

Table 25: 2x2 contingency table for Aspergillus Sensitisation (IgE) and Asthma Status

Fisher's Exact Test, used here rather than the Pearson's Chi-Squared test because an expected cell count was less than 5, identified a statistically significant association between a diagnosis of asthma and being sensitised *to Aspergillus fumigatus* (p=0.026). The Phi value was 0.235 (p=0.013).

Of the 4 individuals assessed to be taking medications or have underlying medical conditions associated with immunosuppression, all worked in potentially high-exposure jobs as operators on open-windrow composting sites. The first (as assessed chronologically) had worked for 9 years in the industry and was found to be sensitised by SPT to *Aspergillus fumigatus* but none of the other agents tested in this study. He reported eye and nose symptoms that improved when away from work but did not declare a history of asthma or chronic lung disease.

The second individual had worked in the compost industry for 8 years. He reported eye, nose and chest symptoms that improved away from work, including chest tightness and a persistent cough with phlegm. His most recent spirometry result was reported as normal for age and gender by his occupational health provider, but there was not sufficient longitudinal data to examine the rate of decline of lung function. He was not found to be sensitised to any of the agents tested either by skin or blood. He had worked in the compost industry for 26 years. The third immunosuppressed worker reported no symptoms and had a negative set of tests and had worked in the industry for several years. The fourth, who had had splenectomy in 1982, was sensitised to *Aspergillus fumigatus* by SPT but not to other agents. He reported no symptoms but had only worked in the industry for one year.

5.8. Use of RPE

During the site visits, data about the types of RPE offered to employees, compliance and reasons for non-compliance were captured when administering the questionnaire to the volunteer participants. Fifty-six out 111 (50.5%) of workers stated that they were offered and wore RPE, of which 47 (83.9%) worked predominantly in potentially high-exposure roles such as operative duties in producing compost or cleaning/litter duties around the compost piles. The main reason why outdoor windrow workers stated they wore RPE was for servicing vehicles; cleaning cab filters which required 'shaking' the filter so that material would fall out and/or spraying the filters with water to remove debris, or for work near compost piles that was not performed in a cab such as litter duties. No individuals reported wearing additional RPE when driving tractors or cabs or when walking around the site. In indoor sites, workers also reported wearing RPE when entering tunnels to place environmental probes or to conduct compost sampling activities.

A wide array of RPE was offered to employees across the six companies involved. None were offered simple cloth or fabric face masks. Forty-eight out of the 56 workers (85.7%) stated that they had access to disposable half-mask respirators for high exposure tasks. Three individuals stated that they wore half-mask filtered respirators (as opposed to disposable apparatus) and another three stated that had been provided with both options. Two indoor workers stated that they had been provided air-fed helmets which they used when entering the tunnels for manual activities. The most commonly recorded reason for non-compliance with using RPE was due to thermal or visual discomfort, such as whilst wearing the mask in hot conditions. This was particularly the case in indoor sites, where workers complained of high levels of humidity during periods of high processing activity. Physical discomfort from ill-fitting masks was mentioned by some workers (11/56). One company did not have a requirement for workers to wear RPE for less than 15 minutes of exposure.

5.9. Health Surveillance

During the visits, safety managers were asked to comment on the health surveillance provided for company employees, what they understood the process to entail, and what further information they would like to guide them about how to go about conducting health surveillance in practice. A seven-item questionnaire was sent regarding this issue to all company members of the REA but unfortunately only eight responses were received and as such no meaningful analysis could be undertaken.

Nonetheless, it was evident that health surveillance practices varied across the six companies. One company had only recently instituted health surveillance, and at the time of the study, the safety manager was unable to describe what the proposed health surveillance was to entail. The manager stated that he was reliant on the OH provider having enough knowledge of what surveillance to perform and how and when to do it. The safety manager at a different company stated that they informed their OH provider as to when they wanted their surveillance to take place but received no medical advice as to the frequency at which this should occur. I was informed that employees received 'health screening' in a 'mobile van' to include blood pressure, weight and body mass index analysis with subsequent lifestyle advice if appropriate such as smoking cessation, diet and exercise recommendations. Employees were also offered spirometry and the company was provided with a report simply stating whether an individual's results were satisfactory or required further investigation. Another company had more structured health surveillance with a yearly respiratory questionnaire to enquire about work-related respiratory symptoms and spirometry. The OH manager told me that they had considered doing some work examining sensitisation to bioaerosol components using skin prick tests, but at the time of the study had not yet progressed this.

In summary, there appeared to be a range of health surveillance practices across the six companies involved from none to yearly questionnaires with spirometry. I did not encounter any OH providers who were routinely testing workers for sensitisation by either SPT or blood, despite previous recommendations to this effect (Poole & Wong 2013). Neither was there evidence that the OH providers were analysing spirometry results on a longitudinal basis to look for decrements in lung function that may exceed normal parameters for age, sex and height as well as smoking status.

Chapter 6: Questionnaire Evaluation

6.1. Introduction

Several previous studies have used health questionnaires to assess the presence of symptoms that may be related to compost exposure. Few however have specified what questions were asked or how they were completed. Such detail is important in appreciating their validity, reliability and generalisability to other settings. A health surveillance program for workers in this sector would undoubtedly benefit from the inclusion of a standardised questionnaire, providing a time and cost-effective means for capturing health information. Bioaerosol exposure is also known to occur in several other industries. These include the poultry, farming, grain and animal feed, baking (through flour and bacterial enzyme exposure), cotton and textile, wood and paper recycling industries. It is therefore conceivable that such a questionnaire could be of value more widely. For instance, the HSE recommends annual health questionnaires for workers in the grain industry, though it is not clear what questions should be asked.

Standardised questionnaires to assess symptoms of respiratory illness already exist such as the British Medical Research Council Respiratory Questionnaire and the St George's Respiratory Questionnaire (Minette 1989; Jones et al 1991). Nonetheless, a review of health surveillance programmes for occupational respiratory diseases identified wide variations in the types of questionnaires used in different industries in the UK (Lewis & Fishwick 2013). The concerns about the heterogeneity of health questionnaires found in that review parallel those of my systematic review of occupational illness in the composting sector.

The questionnaire used in this study was a modified version of one used by the Health and Safety Executive in previous research. The modifications were primarily made to take account of the different health outcomes which may be associated with bioaerosol exposure as opposed to inorganic dusts. Accordingly, questions assessing possible symptoms of EAA, ODTS and ABPA were added, as well as questions about possible work-related dermatitis. The questionnaire was also kept concise to minimise the amount of time workers spent away from their jobs.

Collection of these data provided an opportunity to test the properties of the questionnaire to determine whether if it could be of value without amendments or if it suffered flaws in structure which could lead to overlap between symptom domains which may generate non-specific or erroneous results. In this section, I shall describe my approach towards examining this. Importantly, this method does not confirm the predictive value of the questionnaire in diagnosing illness, rather to identify its fundamental abilities to group symptom clusters appropriately using the least number of appropriate questions. Prior to this however, a discussion of the key terms and concepts which underpin such an analysis is necessary. I shall therefore initially provide an overview the general approaches that can be used to examine the validity and reliability of questionnaires, including some definitions of the terminology used in this field.

6.2. Validity and Reliability

Validity and reliability are measurement properties of an instrument (Golafshani 2003). Validity is defined as the ability of an instrument to measure what it is supposed to measure. Typically, this is subdivided into several categories namely content validity, criterion validity and construct validity. Content validity examines the extent to which an instrument covers a representative sample of the domains under investigation (Haynes et al 1995). In this study, a relevant description would be the degree to which the questionnaire captured the spectrum of illness and health symptoms associated with bioaerosol exposure. Criterion validity reflects the use of a well-established measurement tool (a criterion) to create a new measure of the area of interest (Murphy & Davidshofer 1988). Reasons to do this in practice include the development of a shorter version of an existing questionnaire or to examine the performance of a questionnaire in a different context or setting. Criterion validity has two components; concurrent and predictive validity. To assess concurrent validity, statistical methods are usually employed to determine whether a new instrument is closely correlated with an existing instrument. The existing instrument is usually a 'gold-standard' in the field. Predictive validity refers to the degree to which an instrument can predict future performance or outcomes. A health-related example is to examine the relationship between currently reported symptoms and future clinical disease, and thus may take many years to establish.

Convergent validity examines the degree to which two measures that theoretically should be related, are related. On the contrary, divergent validity examines whether two theoretically unrelated measures are in fact unrelated (Campbell & Fiske 1959). An example of convergent validity could be to determine whether two sections of a questionnaire where answers should be closely related are in fact so, such as questions measuring job satisfaction and job wellbeing for example. Statistical correlations can be calculated to this effect. Nonetheless, if satisfaction was also closely correlated with negative wellbeing, then this would bring the questionnaire's convergent validity into question. Lastly, a 'construct' is a notion which is used in everyday language to express ideas about a subject of interest. The purpose of this is to share meaning. These constructs might include opinions about people such as their race, age or gender; events such as famine or war, or discourse about politics and socioenvironmental issues. Accordingly, construct validity assesses the overall validity of an instrument in measuring a given trait (Cronbach & Meehl 1955). To this end, it is an overarching term which incorporates other forms of validity such as content, criterion, convergent and divergent validity.

Reliability refers to the ability of an instrument to provide consistent results if it were to be used repeatedly. There are a few approaches to assessing an instrument's reliability of which a commonly used method is classical test theory (Crocker & Algina 1986). This assumes that each respondent has an innate true score, and the observed score only differs from this because of random error. Classical test theory however assumes that over infinite administrations of an instrument, random error will cancel itself out. As systematic errors act in a single direction, they are deemed not to affect the reliability of the test because they are essentially 'absorbed' into the true score. Other means to assess the reliability of an instrument include inter-rater reliability, test-retest reliability, parallel forms reliability and internal consistency of which the latter will be discussed here (Cohen et al 1996). The internal consistency approach examines how closely items that are related to the same construct provide similar results. There are four commonly applied methods. The first is to calculate an average inter-item correlation, in which correlation coefficients are calculated for each pair of items measuring similar constructs. For illustration, if six items on a questionnaire are designed to capture symptoms which may relate to the presence of occupational asthma, this generates 15 separate pairings. The coefficients for these pairings are then averaged to provide the final figure. A modified approach of this is the average item-total correlation which in the latter example would involve the calculation of a total score for each of the six items. This total score is used as a seventh variable to calculate an average figure. The third, split-half approach randomly divides all the items that are thought to measure the same construct into two halves (Kuder & Richardson 1937).

The instrument is administered to a group of people and the total score is calculated for each half of the test. The overall reliability is the correlation of scores between the two halves. Once again however, dividing tests into halves in such a fashion may be problematic if the two split-halves are not equivalent, or if the two halves contain only a few items.

Although statistical methods, such as the Spearman-Brown equation can be used to 'offset' the difficulties in using a split-half method by estimating the reliability of the test if the two halves were increased in length, an alternative method to address this issue is that of Cronbach's Alpha (α). This approach derives reliability estimates from a single test form, and calculates internal consistency based on the average correlations amongst all the items in the instrument (Novick & Lewis 1967). The α value is derived from all the possible 'split-halves' that can be drawn out of the instrument and lies between 0 and 1, with zero indicating complete unreliability and one indicating complete reliability. By convention, an instrument with an α value of >0.9 is usually considered to have excellent reliability, with a value between 0.8-0.9 classed as 'good', 0.7-0.8 as 'acceptable', 0.5-0.7 as 'poor' and <0.5 'unacceptable' (Tavakol & Dennick 2011). It has been suggested that α may be underestimated where multiple constructs are being measured and thus some have advised reporting separate α coefficients for each construct (Tavakol & Dennick 2011). Nonetheless, where constructs are short this may not always be appropriate, for example if a subscale only contains a couple of items.

6.2. Methods

The aim of this study was to identify whether the health questionnaire suffered from structural difficulties from which non-specific or erroneous results may arise. The approach that I used to examine this was that of a Principal Components Analysis (PCA) (Yong & Pearce 2013). It was conducted with support from a statistician (Gillian Frost) and work psychologist (David Fox) at the Health and Safety Executive Laboratory, Buxton using the steps described above. Responses from each item of the questionnaire were initially standardised into an ordinal scale. I subsequently calculated Spearman's correlation coefficients (r) for each item to establish which sets of questions were perfectly correlated (r=1.0). Where two or more items were perfectly correlated, these were excluded from the PCA to avoid multicollinearity. Multicollinearity is a statistical phenomenon known to inappropriately influence the strength of regression coefficients and reduce the precision of regression coefficients when other variables are added to a model (Farrar & Glauber 1967). Once perfectly correlated items had been removed, we calculated correlation matrices with eigenvectors and eigenvalues for each of the principal components. These values are typically used to determine which components should be retained and rejected from the analysis. A cut-off value of 1 or above for retaining a component was set as per the Kaiser-Guttman criterion (Joliffe 2002). The theory behind retaining such components is that they should account for more of the variance in the dataset than any single individual variable. Therefore, components with 'better than average' variance (eigenvalues greater than 1) should be retained (Nunnally & Bernstein 1994). For additional reassurance, a scree plot was created with component numbers plotted on the x-axis against eigenvalues on the y-axis. It has been recommended that components above the point of inflexion on the graph should be retained (Cattell 1966).

The next stage involved determining how the retained items from the PCA loaded onto the identified components. This was a mathematical approach to weigh-up the ‘contribution’ of an item to interpreting the component. To achieve this, a rotated component matrix was used. A lower limit of 0.4 was set as the minimum loading value an item should have to be contributing significantly to that component (Stevens 1992). In this context, a loading value can be considered as equivalent to a correlation. A ‘check’ was then conducted to ensure that none of the identified components were significantly correlated with each other. To conclude the evaluation of this questionnaire, I conducted a reliability analysis using the data from the PCA. Cronbach’s Alpha values were calculated for each item in the manner described earlier, as well as for each of the component subscales.

Once the principal components of the questionnaire had been finalised through discussion with DF and GF, I named each component according to the clinical theme which they encompassed. Finally, I reviewed omitted questions to determine whether any had additional clinical value to the outputs from the PCA, and if so, I reinstated them in the final version of the questionnaire. Data were handled using STATA Version 11.0, SPSS Version 22.0 and Microsoft Excel. All data was completely anonymised at the time of entry into the datasheets. Datasheets were kept on a secure server at the Health and Safety Laboratory, Buxton and on a password-encrypted memory stick when data was analysed off-site. The ethical approval process for the study has already been described.

6.3. Results

The table below displays all of the 46 binary-answer items contained within the original questionnaire administered to the volunteer workers in this study. The questions listed below are therefore the same as those found in the copy of the questionnaire in the Appendix, although numbered differently. Questions requiring free-text answer such as 'how long after the starting week did these occur?' and 'how long do the symptoms usually last' were not included in the PCA. Items in italics are those in which the wording of the original HSE question was amended or reflect questions that were added by me or Dr. Jon Poole prior to administration. Questions about gastrointestinal symptoms, although reported to be higher in these workers, were dropped due to their lack of specificity.

Question
1. Have you ever been diagnosed by a doctor with asthma?
2. Have you ever been diagnosed by a doctor with chronic obstructive pulmonary disease?
3. Have you ever been diagnosed by a doctor with another chest problem such as cystic fibrosis, bronchitis or bronchietasis? (ask details)
4. Have you ever been diagnosed by a doctor with eczema?
5. Have you ever been diagnosed by a doctor with hay fever?
6. Have you ever been diagnosed by a doctor any form of allergy? (e.g peanut, egg etc.) (ask details)
7. Do you take medicines for asthma such as inhalers, aerosols or tablets?
8. Do you smoke *outside of work*?
9. In the last 12 months has your chest become tight?
10. In the last 12 months have you been woken up because of chest tightness?
11. Do you only get chest tightness with colds?
12. Is your chest tightness better, the same or worse away from work?

13. Is your chest tightness better, the same or worse on holiday?
14. In the last 12 months have you had shortness of breath when walking or at rest?
15. In the last 12 months have you been woken up because of shortness of breath?
16. Do you only get shortness of breath with colds?
17. Is your shortness of breath better, the same or worse away from work?
18. Is your shortness of breath better, the same or worse on holiday?
19. In the last 12 months have you experienced wheezing or whistling in your chest?
20. In the last 12 months have you been woken up with wheezing or whistling in your chest?
21. Do you only get chest wheezing or whistling with colds?
22. Is your wheezing or whistling better, the same or worse away from work?
23. Is your wheezing or whistling better, the same or worse on holiday?
24. In the last 12 months have you had a cough that has kept you awake at night?
25. Do you usually cough first thing in the morning in winter?
26. Do you usually cough at other times of the day or night in winter?
27. Do you usually bring up any phlegm from your chest when you cough?
28. Do you cough like this on most days for as much as three months of the year?
29. Have you ever coughed up any green plugs or brown strings?
30. Is your cough better, the same or worse away from work?
31. Is your cough better, the same or worse on holiday?
32. In the last 12 months have you had unexplained weight loss?
33. In the last 12 months have you had unexplained flu-like symptoms?
34. In the last 12 months have you had unexplained fevers?
35. In the last 12 months have you had unexplained shivering?
36. In the last 12 months have you had unexplained joint or muscle aches?
37. In the last 12 months have you had unexplained general feelings of being unwell?

38. Do you ever suffer from irritation of your eyes such as pricking, itching, burning, dryness, watering, soreness or stinging of the eyes?
39. Is/was your eye irritation better, the same or worse away from work?
40. Is/was your eye irritation better, the same or worse on holiday?
41. Apart from when you have a cold, do you ever suffer from irritation of your nose such as pricking, itching, burning or a runny, dry or blocked nose?
42. Is/was your nose irritation better, the same or worse away from work?
43. Is/was your nose irritation better, the same or worse on holiday?
44. Do you have, or have you ever had a rash that you attribute to work?
45. Does your rash get better, stay the same or get worse away from work?
46. Does your rash get better, stay the same or get worse on holiday?

Table 26: Initial questions selected for PCA

The Spearman's correlation coefficients calculated for each of the 46 items identified that several were perfectly correlated which are shown in the table below:

Q10. In the last 12 months have you been woken up because of chest tightness? = Q20. In the last 12 months have you been woken up with wheezing or whistling in your chest?
Q12. Is your chest tightness better, the same or worse away from work? = Q13. Is your chest tightness better, the same or worse on holiday? = Q17. Is your shortness of breath better, the same or worse away from work? = Q18. Is your shortness of breath better, the same or worse on holiday?
Q22. Is your wheezing or whistling better, the same or worse away from work? = Q23. Is you wheezing or whistling better, the same or worse on holiday?
Q29. Have you ever coughed up any green plugs or brown strings? = Q32. In the last 12 months have you had unexplained weight loss?
Q30. Is your cough better, the same or worse away from work? = Q31. Is your cough better, the same or worse on holiday?

Q33. In the last 12 months have you had unexplained flu-like symptoms? = Q35. In the last 12 months have you had unexplained shivering? = Q36. In the last 12 months have you had unexplained joint or muscle aches? = Q37. In the last 12 months have you had unexplained general feelings of being unwell?
Q39. Is/was your eye irritation better, the same or worse away from work? = Q40. Is/was your eye irritation better, the same or worse on holiday?
Q42. Is/was your nose irritation better, the same or worse away from work? = Q43. Is/was your nose irritation better, the same or worse on holiday?
Q45. Does your rash get better, stay the same or get worse away from work? = Q46. Does your rash get better, stay the same or get worse on holiday?

Table 27: Question sets with perfectly positive Spearman correlation coefficients

Questions 10, 12, 22, 29, 30, 33, 39, 42 and 45 were retained from those listed in the table above. Using a threshold value of greater than 1, the eigenvalues indicated that nine components should be retained from the questionnaire:

Component	*Eigenvalue*	*Proportion of Variance Explained*
1	5.12	0.18
2	3.85	0.14
3	2.92	0.10
4	2.26	0.08
5	1.89	0.07
6	1.65	0.06
7	1.48	0.05
8	1.25	0.04
9	1.15	0.04

Table 28: Eigenvalues for Questionnaire Components

The table shows the eigenvalues for the components retained in the PCA. The results indicated that nine components had eigenvalues greater than 1 (Kaiser-Guttman Criterion)

As a further check, a scree plot was conducted to examine where the first 'point of inflexion' occurred with respect to the eigenvalues generated for each of the 28 items retained in the PCA. The horizontal line parallel to the x-axis in the graph below indicates this first point of inflexion, with 9 points remaining above the line on the y-axis, corroborating the findings from the PCA.

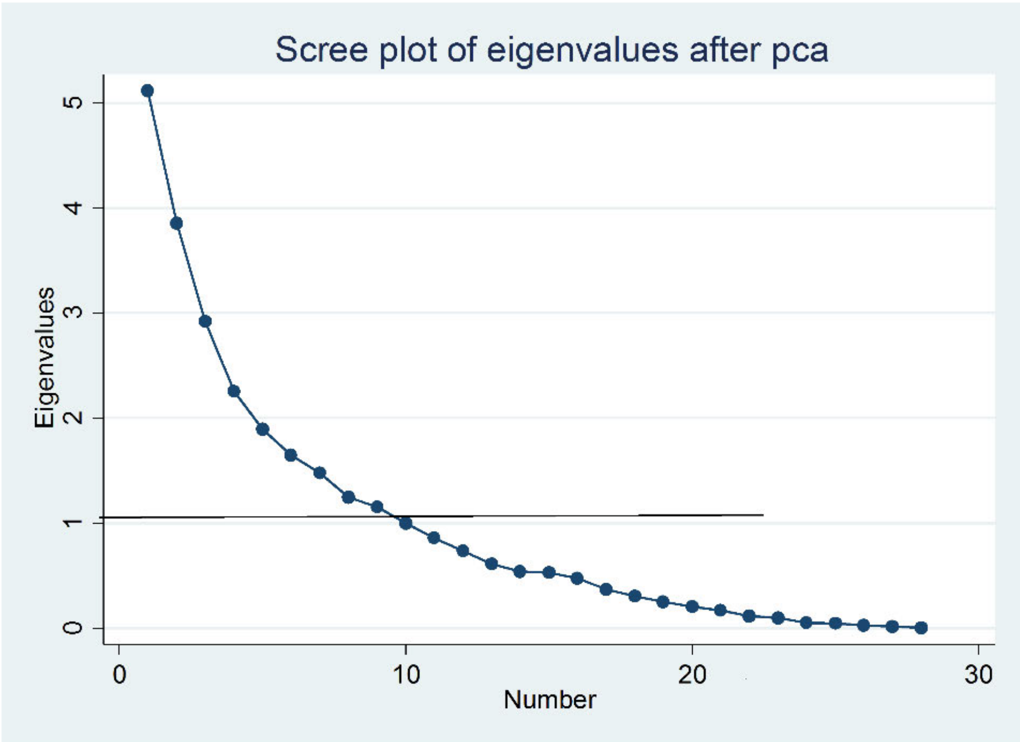

Image 12: Scree Plot of Eigenvalues after PCA

The image shows the data from in graphical form, indicating that 9 components should be retained.

The next step of the PCA was to determine how the items used in the PCA loaded onto the nine components. A factor loading cut off criterion of > 0.4 was set, with the pattern below identified. No cross-loading of questions, in which one question was loaded onto two or more components, was observed. The question numbers in the left-hand column of the table are as of the org, with perfectly correlated questions excluded to avoid multicollinearity. I subsequently named each of the components based on the clinical themes of the questions that were loaded onto them.

Question	Comp 1	Comp 2	Comp 3	Comp 4	Comp 5	Comp 6	Comp 7	Comp 8	Comp 9
Q1	-0.05	0.25	-0.06	0.11	0.01	0.02	0.39	0.13	-0.28
Q2	-0.06	-0.06	-0.01	-0.01	0.01	-0.04	0.03	**0.66**	-0.02
Q4	-0.01	0.04	0.10	-0.03	0.16	0.03	0.19	0.05	**0.61**
Q5	-0.06	-0.05	0.10	-0.03	0.16	0.04	0.19	0.21	0.03
Q6	0.05	0.02	-0.01	-0.10	-0.03	-0.07	**0.64**	-0.04	0.10
Q7	-0.05	0.39	-0.01	0.08	0.00	0.04	0.12	0.17	-0.20
Q8	0.32	0.00	0.09	-0.15	0.02	-0.23	0.07	-0.05	0.00
Q9	-0.04	0.26	**0.45**	0.06	-0.02	-0.04	-0.07	0.07	-0.03
Q10	0.02	**0.47**	0.11	-0.07	0.05	0.10	0.09	0.03	-0.04
Q11	0.04	-0.30	-0.27	-0.12	0.00	0.08	0.16	0.23	0.04
Q12	-0.02	-0.12	**0.58**	0.12	-0.01	0.07	-0.06	0.08	-0.05
Q14	0.06	0.07	**0.46**	-0.10	0.01	-0.04	0.08	-0.26	0.05
Q15	0.02	**0.41**	0.04	-0.15	0.00	-0.09	0.08	-0.02	0.14
Q16	0.07	0.05	0.01	-0.04	-0.09	0.06	-0.02	0.04	-0.10
Q19	0.16	0.21	**0.41**	0.06	0.04	0.03	0.04	0.10	-0.05
Q20	0.01	**0.51**	-0.03	0.03	-0.02	0.02	-0.02	0.03	0.04
Q21	-0.06	-0.31	0.05	0.12	-0.01	-0.25	-0.02	0.38	-0.14
Q22	-0.04	0.04	-0.06	-0.06	-0.07	**0.61**	-0.07	-0.01	0.05
Q24	0.15	0.12	-0.06	0.10	0.10	0.39	-0.13	0.02	-0.16
Q25	**0.46**	0.07	-0.11	0.06	-0.00	0.10	0.01	0.05	-0.03
Q26	**0.43**	-0.06	0.06	0.04	0.01	0.10	0.03	0.01	0.01
Q27	**0.48**	0.00	-0.05	0.06	0.03	0.03	-0.06	0.05	-0.02
Q28	**0.47**	-0.04	0.07	0.00	-0.05	-0.16	0.05	0.04	0.01
Q29	-0.03	0.03	0.07	-0.11	**0.59**	0.01	-0.09	0.24	0.17
Q30	0.01	-0.14	0.26	-0.02	-0.05	**0.50**	0.00	0.05	0.03
Q33	0.03	-0.03	-0.06	0.08	**0.51**	0.00	0.02	-0.26	-0.11
Q34	0.01	-0.05	-0.07	0.13	**0.51**	-0.03	0.02	-0.21	-0.11
Q38	-0.06	-0.14	-0.02	0.26	-0.09	0.14	**0.43**	-0.13	-0.02
Q39	0.05	0.01	-0.03	0.04	-0.08	0.02	**0.44**	0.00	-0.06
Q41	0.02	0.00	0.05	**0.59**	0.02	-0.03	0.03	0.02	0.07
Q42	0.04	0.02	0.07	**0.58**	0.03	-0.04	-0.05	0.00	0.10
Q 44	-0.01	0.09	-0.18	0.23	-0.15	0.00	-0.11	-0.03	**0.59**
Q45	-0.07	0.06	-0.20	0.11	-0.12	0.29	-0.08	-0.11	0.20
Themes	Bronchitis	Woken up by chest complaint	Chest Symptoms	Nasal irritation	EAA, ODTS & ABPA	Work related chest Sx	Eye irritation	COPD	Eczema

Table 29: Loadings of PCA items onto final components

The table shows the loading of each of the retained items in the PCA onto the nine retained components which were named as displayed on the bottom row. Values greater than 0.4 (marked in bold) indicate significant loading onto that component.

A component rotation matrix using an Oblique Oblimin algorithm was formed. Oblique oblimin rotations, as opposed to orthogonal rotations, allow for potential correlation between components, and was therefore applied here to determine if any of the identified nine components were very strongly correlated with each other. Although some relationships existed (such as between component 3 and 5 with a value of 0.62) none were perfectly correlated, and most were quite weak (<0.5).

In the final step, I reviewed questions that had been omitted from the PCA due to multicollinearity to establish whether one or more of these items added clinical value to the questionnaire containing the nine components described. Four questions which were part of the original questions but had been removed prior to the PCA were reintroduced for this reason. These questions were:

- Have you ever been diagnosed by a doctor with another chest problem?
- Is your shortness of breath better, the same or worse away from work?
- In the last 12 months have you had any unexplained weight loss?
- In the last 12 months have you had any unexplained joint or muscle aches?

It was noted that questions which may pick up the presence of underlying conditions such as cystic fibrosis or bronchiectasis were missing following the PCA. Such questions are of clinical importance, since these workers may be at higher risk of developing occupational respiratory illness from bioaerosol exposure. Additionally, questions asking about changes in shortness of breath away from work or on holiday were missing, and therefore I deemed it prudent to reintroduce at least one. The final two questions were reinstated due to their possible specificity for rarer conditions secondary to bioaerosol exposure such as EAA, ODTS and ABPA,

The final 37-item questionnaire is shown below.

Question
1. Have you ever been diagnosed by a doctor with asthma?
2. Have you ever been diagnosed by a doctor with chronic obstructive pulmonary disease?
3. Have you ever been diagnosed by a doctor with another chest problem? (ask details)
4. Have you ever been diagnosed by a doctor with eczema?
5. Have you ever been diagnosed by a doctor with hay fever?
6. Have you ever been diagnosed by a doctor any form of allergy? (ask details)
7. Do you take medicines for asthma such as inhalers, aerosols or tablets?
8. Do you smoke *outside of work*?
9. In the last 12 months has your chest become tight?
10. In the last 12 months have you been woken up because of chest tightness?
11. Do you only get chest tightness with colds?
12. Is your chest tightness better, the same or worse away from work?
13. In the last 12 months have you had shortness of breath when walking or at rest?
14. In the last 12 months have you been woken up because of shortness of breath?
15. Do you only get shortness of breath with colds?
16. Is your shortness of breath better, the same or worse away from work?
17. In the last 12 months have you experienced wheezing or whistling in your chest?

18. In the last 12 months have you been woken up with wheezing or whistling in your chest?
19. Do you only get chest wheezing or whistling with colds?
20. Is you wheezing or whistling better, the same or worse away from work?
21. In the last 12 months have you had a cough that has kept you awake at night?
22. Do you usually cough first thing in the morning in winter?
23. Do you usually cough at other times of the day or night in winter?
24. Do you usually bring up any phlegm from your chest when you cough?
25. Do you cough like this on most days for as much as three months of the year?
26. Have you ever coughed up any green plugs or brown strings?
27. Is your cough better, the same or worse away from work?
28. In the last 12 months have you had unexplained weight loss?
29. In the last 12 months have you had unexplained flu-like symptoms?
30. In the last 12 months have you had unexplained fevers?
31. In the last 12 months have you had unexplained joint or muscle aches?
32. Do you ever suffer from irritation of your eyes such as pricking, itching, burning, dryness, watering, soreness or stinging of the eyes?
33. Is/was your eye irritation better, the same or worse away from work?
34. Apart from when you have a cold, do you ever suffer from irritation of your nose such as pricking, itching, burning or a runny, dry or blocked nose?
35. Is/was your nose irritation better, the same or worse away from work?
36. Do you have, or have you ever had a rash that you attribute to work?
37. Does your rash get better, stay the same or get worse away from work?

Table 30: 37-Item Final Questionnaire

6.4. Reliability Analysis

The α values for the nine individual components are shown below, along with the questions loading onto the components. I was unable to calculate an α value for component 8 as there was only one question loading onto this component. The α values for components 1 to 6 are very good or excellent but much lower for components 6,7 and 9.

Component	Description	Alpha
1	Bronchitis (Q25 Q26 Q27 Q28)	0.93
2	Woken up by chest complaint (Q15 Q20)	0.80
3	Chest symptoms (Q9 Q12 Q14)	0.80
4	Nasal irritation (Q41 Q42)	0.96
5	EAA, ODTS & ABPA (Q29 Q33 Q34)	0.80
6	Work-related chest symptoms (Q22 Q30)	0.57
7	Eye Irritation (Q6 Q38 Q39)	0.66
8	COPD (Q2)	N/A
9	Eczema (Q4 Q44)	0.34

Table 31: PCA components with associated Cronbach's α values

The table displays the Cronbach's α values for the nine PCA components along with the questionnaire items which load onto them. Components 1 to 6 had very good or excellent reliability, whereas 6,7 and 9 had lower reliability.

I subsequently conducted a reliability analysis for the final questionnaire following the PCA using the same approach. The α value for the final 37 item questionnaire was 0.78.

6.5. Discussion

My evaluation of the health questionnaire used in this study has established its psychometric properties. It is a content valid and sufficiently reliable instrument to assess workers' health symptoms in this industry. Such an instrument should be of value to the occupational health community, particularly those involved in health surveillance for at risk workers, wishing to investigate possible cases of occupational illness or for research purposes. In this study, several workers expressed gratitude that someone was taking an interest in their health and told me that they felt the questionnaire was easy for them to understand and concise.

The overall reliability of the questionnaire is good but appears to be more reliable for some constructs such as bronchitis and nasal irritation, than for others such as eczema. One reason to explain the high reliability of the component 'bronchitis' relates to the diagnostic criteria for this condition. This includes the presence of persistent morning cough for 3 or more months during the winter, and the questionnaire items in this study were worded to elicit this specifically. Nasal complaints were common in the surveyed workers. Personal protective equipment was worn by all operatives participating in this study in the form of complete body overalls and gloves when handling compost. This may well explain the low numbers of workers complaining of rash, especially perceived work-related rash. The low prevalence of rash and small number of questions loading onto this component therefore may explain the observed α value.

There are several limitations of the approach I have used to evaluate this questionnaire that merit discussion. The first is that the sample size may be considered limited. Some authors have recommended a sample of 300 participants or more with at least 5 to 10 observations when conducting a Factor Analysis (Comrey & Lee 1992). Secondly, the use of the Kaiser-Guttman criterion in which components with an eigenvalue greater than 1 are retained has been challenged. Researchers have indicated that this value may often underestimate (Cattell & Vogelmann 1977) or overestimate (Yeomans & Golder 1982) the number of components or factors that should be retained. Furthermore, it has been shown that the number of components that the Kaiser criterion suggests should be retained is dependent on the number of variables in the instrument and the reliability of the components (Zwick & Velicer 1982). Thus, a blanket eigenvalue of >1 may be inappropriate. A third possible limitation is the use of 0.4 as a minimum cut-off value for component loading, as well as the relatively limited number of variables that loaded onto some of the nine components. Although Stevens (1992) suggests using this cut-off value regardless of sample size, others recommend values of 0.6 when performing factor analyses with small sample sizes (MacCallum et al 1999). Field (2005) suggests that a factor should have at least four factor loadings of 0.6 to be appropriate classified as such. In this study, components 6,7 and 9 had low reliability, but although the items loading onto each component related to the same medical condition, their content was quite different. To illustrate for the two items which loaded onto the component 'eczema', one question asked about doctor-diagnosed eczema and the other as to whether the worker attributed a rash to their work. This contrasts with the component 'bronchitis' for which all 4 loading questions ask about closely related clinical symptoms of the condition. Nonetheless, both questions loading onto the eczema component were important questions to ask, and thus in my opinion, the low reliability should be considered in this light.

Other limitations include the arbitrary names of components. I created these categories based on the clinical content of the items loading onto the specific components, but alternative nomenclature may be appropriate. The choice of questions retained in the final questionnaire following the PCA may also be challenged. The validity of findings from an interviewer-administered format may be challenged, such that decisions about the attribution of symptoms could be influenced by the assessor's interpretation of the participant's responses. Nonetheless, clarification of participant's responses was limited to questions about timings and duration of symptoms, and detail about work activities and locations. As will be discussed in two cases, this approach led to an assessment of the workplace, further medical investigation and a subsequent diagnosis of EAA. I would consider this normal and appropriate occupational health practice. The standardisation of the questionnaire process could be improved further by providing an interviewer manual and instruction set to guide assessors about the type of additional questions to consider when positive responses are given.

Finally, I asked no questions about gastrointestinal symptoms although previous research has suggested there may be an increased prevalence of such symptoms in waste workers as compared to control populations (Ivens et al 1997). Nonetheless, the sensitivity of such questions in distinguishing symptoms of gastrointestinal occupational disease from non-work-related illness merits consideration. In my view, workers may have trouble determining whether such symptoms are ‘worse at work’ or ‘worse on holiday’ when they occur given the difficulties in accurately attributing such symptoms to their job.

It is uncertain at this stage whether this tool is applicable to other industries. Further work could examine the utility, feasibility and acceptability of administering this questionnaire in other workforces, as well as its predictive validity in detecting cases of occupational illness in the composting sector. The latter could only be realistically established using longitudinal approaches. In summary, the PCA applied to the results from this study has identified the core components of a questionnaire which can be used assess the health of industrial compost workers. This questionnaire is concise, content valid and reliable, minimising disruption to work activities whilst enabling the assessor to capture enough medical information to identify possible signs and symptoms of occupational illness in the workforce. Further work should establish the predictive validity of the questionnaire in clinical settings, which may extend beyond the composting industry to other settings where bioaerosol exposure is known to occur.

Chapter 7: Discussion

7.1. Introduction

The structure of this chapter of this thesis is shown below, beginning with a summary of the main findings from this cross-sectional health study. These findings will be then compared and contrasted with those of previous studies in the field, concluding with an analysis of the strengths and limitations of the study.

The final chapter (chapter 5) will describe the potential implications of the findings, discussed in the order of the research question listed earlier. Areas for further work will be examined followed by personal reflections and conclusions regarding the study.

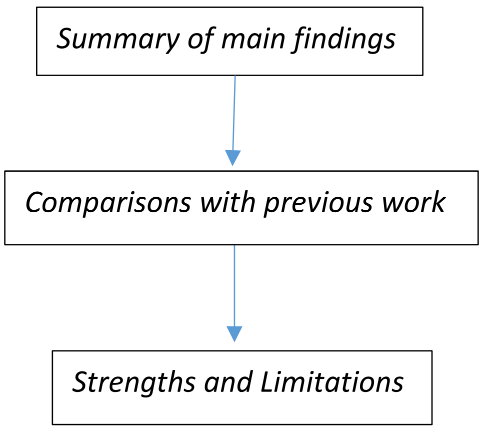

Figure 11: Structure of the Discussion Chapter

7.2. Summary of Main Findings

The main findings and outcomes from the exposure studies and principal components analysis have been described earlier. This section shall summarise the findings from the cross-sectional study of the health of compost workers. The work undertaken for this thesis has shed light on several questions relating to the health of compost workers in the UK industry. The answers to the research questions listed at the end of introduction section are shown below. As will be discussed later, findings here should be viewed as associations and not an inference of causality.

Primary Research Questions

- What is the prevalence of sensitisation to bioaerosols in compost including *Aspergillus fumigatus, Cladosporium herbarum, Alternaria alternata* and *Thermophilic Actinomycetes* in the UK composting workforce?

  The prevalence of sensitisation to the three fungi were 21.6%, 11.7% and 10.8% respectively by SPT. No participants were sensitised by blood IgG to Thermophilic Actinomycetes at a clinically significant level.

- Do those workers sensitised to *Aspergillus fumigatus* by SPT and/or blood IgE report more work-related symptoms that those who are not?

  There were no significant differences in the prevalence of reported symptoms according to Aspergillus sensitisation status.

- Do sensitised workers report more respiratory symptoms than those who are not sensitised?

There were no significant differences in the prevalence of symptoms reported by polysensitised, monosensitised and non-sensitised workers in this study.

- What is the relationship between SPTs and IgE blood tests used to detect sensitisation to bioaerosols in compost workers?

Analysis demonstrated a fair to poor concordance between SPT and specific IgE blood test for fungal antigens found in compost in this study. The implications of these findings are discussed in chapter 5.

Additional Data

- How does the prevalence of reported work-related symptoms and sensitisation compare between those working in high and low exposure jobs?

There were no significant differences in rates of upper airways mucous membrane and lower airways symptoms in high and low exposure jobs.

- How does the sensitisation of reported symptoms and sensitisation vary according to years working in the industry?

Workers who had spent more than 10 years in the industry reported significantly more symptoms of eye irritation than those who had not. There was no significant difference in the rates of reported symptoms in those workers who had been in the industry for more than 10 years according to Aspergillus sensitisation status.

- How does the prevalence of reported symptoms and allergy status compare between those working in outdoor windrow and indoor composting sites?

This study did not detect any significant differences between the prevalence of illness and allergy between outdoor and indoor UK compost workers.

- Asthmatics and Immunosuppressed Workers

Asthmatic workers in this study were more likely to be sensitised to Aspergillus fumigatus than non-asthmatics. Four immunosuppressed workers were identified in the workforce who had not had any specific advice about exposure to high concentrations of bacteria and fungi from the compost.

- The use of respiratory protective equipment and health surveillance practices

The type of RPE worn by workers, undertaking and content of health surveillance was variable between companies. The reasons for this were not clear but may relate to differing levels of understanding regarding the potential health hazards of bioaerosol exposure, differences in compliance and the competencies of the OH providers. Companies that took part in the study were interested in how to better protect their workforce from the adverse health effects of bioaerosol exposure.

There were additional findings of note described below which were not original aims of the study:

- Although the use of SPTs or specific IgE to detect for sensitisation to bioaerosol components has previously been recommended in an academic publication (Poole & Wong 2013); none of the companies in this study were using these tests in their health surveillance for workers.

- Two new cases of EAA were diagnosed during the study. Both workers were sensitised by SPT, specific IgE and IgG to *Aspergillus fumigatus*.

7.3. Comparisons with previous research

Sensitisation

This is the first study to report the prevalence of sensitisation by SPT to fungal antigens in UK compost workers. SPT results from 8 compost workers were reported in a 1994 Danish study of 72 waste workers, with only one testing positive to a skin-prick mixture of common environmental aero-allergens (Sigsgaard et al 1994). Whilst other studies have either asked their participants to self-report their atopy and allergy status or enquired whether they had previously been skin prick tested (Bunger et al 2007); I was unable to find any other publications that had reported the prevalence of sensitisation via SPT in compost workers specifically.

A much larger body of data however is available for specific IgE. Marth et al (1997) reported no statistically significant differences in specific IgE concentrations to fungal antigens in 117 waste workers and controls across five sites in Austria. The authors however did not specify which fungal antigens were tested. Bunger et al (2000) found significantly higher IgG antibody concentrations to *Aspergillus fumigatus* and thermophilic *Actinomycetes spp.* in 58 compost workers as compared to 53 biowaste collectors and 40 unexposed controls. In keeping with findings in this study, a UK study conducted by Jones et al 2011 examined specific IgG levels to *Actinomycetes spp* in a sample of 22 compost workers, finding that all but one worker had detectable levels (>2 mg/L). Van Kampen et al 2012 found no differences in the prevalence of specific IgE sensitisation to *A. fumigatus, C. herbarum, A. alternata* in 190 compost workers as compared to 38 non-exposed controls. My findings are similar but differences in study populations and settings limit meaningful comparisons. The authors also reported that there were no significant differences between compost workers and controls in sensitisation to *S. rectivirgula,* nor were there any significant associations between IgE or IgG levels for any allergens with lung function parameters. Sixteen individuals were classified as sensitised to *S. rectivirgula* when applying a threshold value of 10mg/L using the ImmunoCAP assay. Applying the same cut-off value, only 2 individuals would be sensitised in this UK study to *S. rectivirgula,* although the validity of this comparison is limited by different measurement and analysis methods.

Symptoms

Similar to findings in this thesis, previous work has identified a high burden of ocular, nasal and chest complaints in compost workers. A Danish study including 8 compost workers reported complaints of chronic dry cough and nasal irritation, but low participant numbers precluded relevant statistical comparisons with findings from other studied groups (Sigsgaard et al 1994). An Austrian study of 5 waste sorting facilities, including 1 compost site identified higher odds of eye irritation (OR 6.42), cough (OR 1.42) and respiratory complaints (OR 2.09) than a control group consisting of office workers (Marth et al 1997). The authors did not separate the complaints between workers from the different waste sorting facilities however, and thus data for compost workers were not provided. Bunger et al 2000 identified higher numbers of airway complaints in 58 compost workers than 53 biowaste collectors and 40 less-exposed general population controls, but only differences in symptoms suggestive of tracheobronchitis reaching statistical significance. As generally observed in this thesis, a small cross-sectional study including 31 exposed and 31 non-exposed compost workers also indicated an excess of upper and lower respiratory symptoms in the exposed group (odds ratio 3.7), after adjusting for smoking habits. Higher numbers of gastrointestinal and skin complaints were also reported (Hambach et al 2012). A larger German study identified significantly more reports of watering eyes, and sensation of a foreign body in the eyes in a group of 190 compost workers as opposed to 38 non-exposed controls. In that study, MMI symptoms in compost workers who had left the job resolved, indicating a relationship with continuing bioaerosol exposure (Van Kampen et al 2012). A 13-year longitudinal study examining the prevalence of respiratory symptoms in compost workers also indicated more MMI complaints as compared to controls, with three non-smoking workers reported to have developed chronic bronchitis by the end of the study (Van Kampen et al 2016). Two cases of allergic alveolitis (EAA) were reported. In contrast to the findings from this study, Van Kampen et al 2016 did not find a trend of increasing MMI symptoms of the eyes and nose according to duration of employment, although differences in methodological design (prospective cohort vs cross-sectional) could be a factor. Heldal et al 2015 found a significantly increased frequency of cough in compost plant workers (OR 4.3) as compared to controls in a study in which personal dosimetry was conducted simultaneously with worker examinations. The authors also indicated that work-related cough was most strongly associated with the concentration of *Actinomycetes* spores, as well as cross-shift declines in lung function (FEV_1/FVC). Nonetheless, the relationship between cross-shift acute changes in lung function and long-term longitudinal decline is not clear, and evidence from the woodworking industry suggests that no association exists (Jacobsen et al 2013).

The implications of my findings, in light of the previous research described here, will be discussed in the final chapter.

7.4. Strengths and Limitations of the Study

7.4.1. Strengths

One of the main strengths of this study was the collaboration with industry and trade unions in the design and administration phases. This almost certainly increased interest amongst composting companies and their workforces. Support from the REA allowed access to their media portals (webpage, e-mail, magazine) through which the project was publicised. Managers who were concerned about possible risks from bioaerosol exposure and open to receiving guidance about health surveillance were attracted more easily.

Another strength of this project was in the way in which workers were engaged, which I believe enhanced participation. No worker that was approached refused to take part, with only a small number eventually declining a blood tests due to fear of the procedure as opposed to concern about the possible implications for their job. I spent time with each volunteer explaining the purpose of the work, and the intended benefits for them and the company in helping manage their health and safety. Several of the workers expressed a degree of interest in the work beyond the activities in the cross-sectional health study, such as wanting to understand more about how they might be exposed to bioaerosols during their work and what processes, activities and types of weather may reduce or increase this risk. A genuine interest in the work, coupled with a trust in the researcher helped foster the project's success. An example is that across the study sites, 17 workers initially declined to have their blood taken, but following discussion all but 3 eventually declined to do so once they further understood why this would be helpful. The feedback I have provided to the companies about the study's results has been well-received.

The inclusion of questions to detect systemic symptoms which may be suggestive of EAA, ODTS and ABPA was a useful addition, with the PCA questionnaire evaluation supporting this. The use of a protocol analysis with scientific experts in the field to establish the content validity and practicality of the questionnaire adds credibility to my findings. Additionally, designing the questionnaire in conjunction with industry experts ensured it would be acceptable to management and workers, which has not been reported in previous studies. Also, the questionnaire was completed in an interviewer-administered format. This enabled me to further explore unclear answers or uncertainties about symptom-onset expressed by the worker. An example of this was in determining the work-relatedness of reported symptoms. I was able to go into more detail about exactly when such symptoms arose, during which tasks and how they affected the worker which would not have been possible in a self-administered format, such as if workers expressed that they get ‘short of breath’.

During the study, I visited each site at least once prior to administering the questionnaire and allergy tests. A few sites engaged in mixed recycling processes and I became aware of the possibility that some workers might be encounter exposures other than compost to account for their symptoms, such as where wood and green waste recycling occurred on the same site. Another example is the potential for carbon and nitrogen oxides produced during the IVC process to mimic some of the symptoms encountered through exposure to bioaerosols. Several workers complained of eye and nose irritation whilst working in the composting halls. On further questioning however, it was ascertained that in some individuals these were associated with feelings of dizziness, nausea and in one case, syncope, suggesting gas exposure to chemical agents such as VOCs. This insight into the practices of workers and the interviewer-led format enabled me to clarify specific details regarding the onset of symptoms, such that these could be more appropriately attributed to their likely source of exposure.

The findings from this study provide the largest dataset about the health of UK compost workers so far; and to my knowledge is only second in size to a study of 190 compost workers in Germany conducted a few years ago (Van Kampen et al 2012). Thus, the findings provide useful information to those involved in the health, safety and wellbeing of these workers. The exposure data collected from the indoor and outdoor composting sites were representative of those recorded in the literature. These were operated by large industrial green waste processing companies, with consistent policies and procedures regarding operative practices across their respective sites. There is no reason therefore to believe that the assessed sites were in any way atypical of the exposures encountered by other workers that took part in the study. Whilst, as discussed below, causal relationships cannot be inferred; there is evidence of an association between working in the composting industry and a higher prevalence of respiratory health complaints, of which the implications will be discussed later. This work adds to the existing literature base in this area. This work has also led to the development of a useful piece of technology; that of a concise, reliable questionnaire which could be used to assess health complaints that may be related to bioaerosol exposure from compost.

7.4.2. Limitations

There are several limitations of the methods used in this study that merit discussion. The cross-sectional approach means whilst statistical associations have been identified, causal relationships cannot be drawn. For instance, whilst compost workers that have been in the industry greater than 10 years reported significantly more eye symptoms than those present less than 5 years, no further inferences can be made. Longitudinal cohort studies can examine this relationship further and assess for the presence of a healthy worker survivor effect. Such an effect is noted when those workers with no or less troublesome health complaints remain in the workforce, whereas those with more substantial ill-health leave. This may lead to an underestimation of the strength of the relationship between exposures and outcomes. In this study, no data were obtained regarding former workers' symptoms or sensitisation status. Workers with symptoms may leave the industry or receive medical advice to do so. Evidence to support this assertion may be found in a research study from Germany which indicated that workers leaving the industry suffer from an excess of health complaints, particularly cough with phlegm (Van Kampen et al 2012). Future studies may assess this using an appropriate occupational control group, such as the office-based workers here.

Whilst I have previously noted some of the strengths of the approach used in designing and administering the questionnaire, there are some potential limitations. The criterion validity of some aspects of the questionnaire are not known since there was no 'gold standard' questionnaire by which to compare responses to systemic symptoms which may have been related to EAA, ODTS and ABPA. The cross-sectional approach limited inferences regarding clinical diagnoses. This was particularly relevant for conditions such as occupational asthma and chronic bronchitis, where longitudinal data from investigations such as spirometry or peak flow diaries would have been informative. Retrospective assessment of spirometry results was not possible in this study due to incomplete or inconsistent assessment methods across occupational health providers. The interviewer-administered approach, whilst allowing flexibility, introduces the possibility of interviewer bias such that the responses to questions may have been distorted (Bowling 2005). Specific issues could include the phrasing of questions, particularly ones additional to those on the questionnaire, as well as leading remarks. Some workers commented that their symptoms were present some months' previously in times of higher composting activity which increased the potential for recall bias about their timing and nature.

It is possible the use of a single interviewer as in this case may have offset some of these difficulties. Nonetheless, these remain of concern should the questionnaire be used more widely. One way in which this could be overcome is using a standardised manual such that it is clear to the interviewer what questions should be asked following a particular response or set of responses. Corroborative data where symptoms are reported may also be helpful in addressing concerns regarding interviewer bias. These include physical examination findings, investigation data, as well as information from sickness records. For example, subclinical responses such as inflammatory markers in the nasal or conjunctival fluid, blood, exhaled air may help attribute the presence of symptoms to exposure, as opposed to purely relying on self-report. One such test is that of acoustic rhinometry for assessing nasal inflammation in compost workers, or the serum pneumoproteins CC16 and SP-A as markers of lower airways injury (Heldal et al 2015).

In recruiting participants, despite all reassurances about its transparency, it is possible that some may have felt an obligation to take part in the study due to pressure or perceived pressure from management. Workers may have overstated the severity and frequency of their symptoms for secondary gain, such as financial compensation or to move job tasks, whereas as others may have played them down for fear of losing their job. Nonetheless, the collaboration with independent industry experts may have offset this to a degree. For example, changing the question 'Do you smoke?' to 'Do you smoke outside of work?' to allay workers' concerns that their answers may be used by management for disciplinary purposes.

In administering the SPTs for environmental aero-allergens, cat and dog allergens would normally be included in the European standard assessment panel (Heinzerling et al 2013) and were omitted here due to funding constraints. Thus, it is probable that some sensitised individuals may have been missed in this analysis. Quantifying this is challenging but data from previous studies can provide some insight. A pan-European study (GA^{2}LEN) identified that 31.7% and 21.4% of 127 participants in the United Kingdom were sensitised to these allergens respectively (Heinzerling et al 2009). Nonetheless, the GA^{2}LEN study sampled individuals attending specialist immunology centres. Such individuals may be referred to these centres due to an increased risk, or suspected increased risk of allergy which could predispose them to illness. Data pertaining to cat sensitisation in UK general population is sparse. In the first European Community Respiratory Health Survey (ECRHS I 1991-1993) sensitisation by SPT to cat allergen was 8.8% in 15160 participants across 35 centres in 15 European countries (Bousquet et al 2007). The corresponding prevalence of sensitisation to cat by specific IgE was 8.5% in the 13391 subjects that provided samples (Burney et al 1997). Allergic sensitisation to cat and dog, as assessed by specific IgE, has been noted to be about 12% in 7269 individuals aged 6 or above residing in the United States (Salo et al 2014).

Measurement biases are also a further possible limitation. These include inaccuracies in conducting the SPTs such as in the application of skin droplets; differing allergen potency and stability; variability in skin reactivity between individuals; measurement error in recording wheal diameters, and interviewer errors in noting questionnaire responses such as attributing the 'work-relatedness' of symptoms. Training ensure my competency in conducting SPTs, the use of a single manufacturer and that questionnaire responses were recorded and analysed by a single individual should have provided some consistency. Nonetheless, another measure that could have been taken was to perform dual SPTs for the same allergen for each individual and assess their diagnostic agreement, as has been done previously (Kesphol et al 2016). Corresponding tests could have been performed on each of the volunteer's forearms. This was considered at the design stage but not possible due to budget limitations, such that twice the volume of allergens would have been needed.

The absence of incidence data from cross-sectional design such as this; that is new cases or symptoms over a defined timeframe, brings practical limitations. Such information may be useful, for example in determining the impact of new control measures or different practices on the prevalence of sensitisation or illness. Another limitation is that bioaerosol measurements have only been recorded at a single point in time. It is known that these vary according to environmental patterns and working patterns, but one previous study in the UK suggests that total bioaerosol generation variations according to weather patterns are not significant across seasons (Sanchez-Monedero et al 2005). Longitudinal studies can identify these variations more precisely and would be needed to link exposure to symptoms, and subsequently provide enough evidence to develop workplace exposure limits. Two such future studies are discussed below.

Some analyses were limited to low numbers in categories, such as that relating to the small number of asthmatics. In some cases, whilst combining groups for the purposes of statistical analysis may have been possible, in practice the findings would be less meaningful. Multiple testing may also have led to spurious findings.

Another limitation is the absence of exposure-response data such that symptoms cannot be linked to the presence of a specific bioaerosol component. Endotoxin and β-glucan concentrations were not measured, and there is evidence to suggest that the potency of organic dust in triggering ill-health is related to these components (Smit et al 2006; Sykes et al 2011). Only living cells were counted in this study, and it has been noted previously that inactive and dead cells may cause adverse health effects

(Albrecht et al 2007). Different bioaerosol components induce illness through unique mechanisms, with considerable overlap in clinical manifestations. Understanding these relationships are central to developing meaningful advice for industry in managing bioaerosol exposures. Additionally, information regarding the specific environmental fungi and bacteria to which workers were exposed was not available. Although technology exists and is available in the UK to delineate these exposures further (Strejcek et al 2018), the MALDI-TOF mass spectrometer was not accessible due to funding constraints. Additionally, data was not available regarding the range and concentration of organisms within the compost to which workers may have been exposed. Previous research has identified 49 different species of bacteria in compost, with numbers dominated by Bacillus and Bacillus-like genera (MacCready et al 2013).

It is probable that those companies that took part in the study are amongst the most safety conscious in the industry, with several safety managers indicating an interest in the health and wellbeing of their employees. It should be noted that many green waste recycling sites in the UK do not operate on an industrial scale and may only be run by a handful of workers. Compost processing practices, safety procedures, and controls to exposure such as the use of RPE are uncertain in these locations. Thus, the reported prevalence of symptoms and allergy found in this study might not be generalisable to smaller workforces.

Chapter 8: Interpretation and Implications

The findings regarding the prevalence of sensitisation to *Aspergillus fumigatus*, discordance between SPT and specific IgE tests and symptoms according to sensitisation status, job role and length of time in the industry have implications for the industry and occupational health practice. The discussion which follows should be considered in light of the strengths and limitations of the study described above.

8.1. Sensitisation and Symptoms

Although 18 workers in the highest exposure group were sensitised to *Aspergillus fumigatus* by SPT in this study, differences compared to moderate and low exposure groups were non-significant. Furthermore, this study showed no association between *Aspergillus* sensitisation and symptoms. Sensitisation to *Aspergillus* in compost workers has been of concern in this industry given the link between *Aspergillus fumigatus* and a variety of respiratory diseases (Poole & Wong 2013). Bunger et al (2000) noted that elevated levels of IgG in compost workers to *A. fumigatus* compared to controls corresponded well to diagnoses of clinical illness, but another large study found no differences in IgE or IgG levels between workers and controls. It was noted however that different quantification methods were used (pure cultures vs ImmunoCAP) which might have contributed to these differences (Van Kampen et al 2012). Currently, data regarding sensitisation in compost workers to bioaerosols is limited. Little is known about how workers become sensitised or whether this predisposes individuals to a significant additional risk of disease. There is also limited data on whether the removal of bioaerosol exposures results in symptom improvement or de-sensitisation. There are however case reports of occupational illness in workers sensitised to *A. fumigatus*. Two former compost workers were noted to have left their profession due to EAA and three individuals due to asthma in a large German cross-sectional study (Van Kampen et al 2012). Two cases (both of EAA) were diagnosed in this study. Both were sensitised to *A. fumigatus* but not to other bioaerosol components. The sensitisation status to other bioaerosols in cases documented in the literature is unclear. No workers in this study were found to be sensitised to *Thermophilic Actinomycetes* at a clinically significant level but most had detectable IgG antibodies. Previous research has demonstrated cross-shift impairments of lung function with high *Actinomycetes* spore counts (Heldal et al 2015) but long-term effects are unquantified. Therefore, whilst these cases suggest a potential association between *Actinomycetes* sensitisation and illness, there is insufficient evidence to attribute causality.

Although this study does not suggest workers sensitised to *A. fumigatus* report more work-related symptoms than those who are not, the limitations of the cross-sectional approach used and findings from previous research should be considered. It may remain prudent at this stage to advise companies of a possible additional risk of illness in workers sensitised to *A. fumigatus* through sensitisation-mediated illness. Prospective longitudinal cohort studies would inform this further, including symptom and sensitisation data from those who leave the profession.

If the development of allergic IgE-mediated respiratory illness in compost workers is sequential, such that sensitisation is followed by the onset of rhino-conjunctivitis and then lower airways disease; this may provide suitable opportunities for medical intervention. One approach could be to exclude workers at the onset of lower airways symptoms, but this may be too late. For instance, although the prevalence of rhinitis and conjunctivitis dropped significantly on termination of bioaerosol exposure in a study of 59 former compost workers, complaints of cough and dyspnoea commonly persisted (Van Kampen et al 2012). Nonetheless, the sensitisation status of the former compost workers was unclear and thus further inferences are not possible.

Another approach could be to exclude sensitised workers when they first develop rhinitis or conjunctivitis before the onset of lower airways symptoms. Longitudinal spirometry may pick up greater-than-expected declines in lung function for compost workers compared to the general population. Research examining the utility of longitudinal spirometry has provided mixed results. Two studies indicate more significant declines in lung function parameters over time in compost workers than controls, particularly for FVC% (Bunger et al 2007; Van Kampen et al 2012). Nonetheless, a more recent study suggests no differences between active workers, former workers and general population controls (Van Kampen et al 2016).

Research and practice in other industries where workers may be exposed to respiratory sensitisers may provide some insight as to how health surveillance may be best delivered in the composting sector. The association between sensitisation to platinum salts and occupational asthma is well recognised, with immune surveillance also conducted in the detergent industry (Nicholson et al 2005). Cohort studies indicate that the highest risk of sensitisation to platinum salts is within 500-600 days of beginning industrial exposure, with a range of 4 months to nearly 10 years (Heederik et al 2016). A longitudinal follow-up study of 96 sensitised workers, 92 of whom had been transferred to jobs with very low or no platinum exposure, identified an improvement in the prevalence of rhinitis, conjunctivitis and contact urticaria. Sensitisation by SPT also fell from 86 to 52%, but complaints related to asthma persisted more frequently, despite some improvements in severity. Exposure-response data indicated that current platinum exposure (within the last 2 years) was most likely to predict sensitisation (Merget et al 2017). Current recommendations for health surveillance practice for exposure to respiratory sensitisers in the UK, is to conduct this 6-monthly in the first two years of work and annually thereafter. It has been recommended that workers with rhinitis undergo more frequent health surveillance (Nicholson et al 2010).

Merget et al 2017 challenge the notion that removal of workers immediately after the onset of symptoms is sufficient to prevent chronic asthma in the platinum industry, and recommended removal of workers from exposure following a positive SPT. A recent UK Supreme Court judgement declared that platinum sensitisation alone, in the absence of symptoms, is classifiable as a personal injury (UK Supreme Court 2018*)*. The Supreme Court upheld the claimants' case that sensitisation to platinum salts meant that they could not continue with their usual employment. The impact of sensitisation was therefore deemed more than negligible, resulting in a restriction on the employees' earning capacity. The court concluded that actionable personal injury includes an 'asymptomatic physiological change that causes the claimant a real loss of amenity'. It is not clear what the implications of such a judgment may be. Some have been discussed in a recent editorial (Cullinan & Nicholson 2018), including the potential exclusion of sensitised workers from the workforce and implications for health surveillance practice. There is evidence to support a high predictive validity for sensitisation to platinum by SPT and subsequent allergic asthma (Calverley et al 1995). This relationship between sensitisation and ill-health with further exposure to platinum salts may have at least in part informed the view that there was a 'real loss of amenity' in this case. In the absence of such high-quality exposure-response data in the composting industry however, one cannot currently quantify whether sensitised workers in the composting industry should be excluded from certain tasks or jobs. Therefore, judging whether sensitisation to bioaerosol would lead to a 'real loss of amenity' is less clear. Furthermore, there may be opportunity to redeploy sensitised workers to non-bioaerosol exposed roles. It is also noted that the use of longitudinal spirometry to detect changes in lung function may also have legal implications. One example is of employers' liability for actionable injury should accelerated lung function decline influence workers' tenure.

Bioaerosol exposure is associated with conditions such as EAA, ODTS and ABPA. Type I, III and IV allergy mechanisms are relevant, and further work may identify whether there is a sufficient strength of association to demonstrate that working in the composting industry predisposes individuals to these illnesses. Evidence for the utility of longitudinal spirometry in the composting industry is mixed. In my opinion however, there is probably insufficient evidence currently to recommend against its inclusion on the basis of one study (Van Kampen et al 2016). The recommended frequency of health surveillance for compost workers is also uncertain, but one comparable to existing practice for respiratory sensitisers in the UK would not seem unreasonable in the absence of more definitive supporting data.

Despite the scientific uncertainty as how to advise employers about health surveillance for compost workers, it is possible as an occupational physician I may be asked to do this. Considering the limitations in exposure-response data, the cross-sectional approach of most studies and the legal, ethical and occupational implications of different health surveillance practices; it is my view that this should ideally consist of a health questionnaire such as the one administered here; skin-prick tests to *A. fumigatus* on a regular basis and common aero-allergens at baseline, as well as longitudinal lung function. Given the higher numbers of workers that were found to be sensitised using SPT and the low numbers (3 individuals) that had a positive specific IgE and negative SPT to *A. fumigatus*; in a screening programme such as health surveillance it may be acceptable to reserve specific IgE testing for when SPT is contraindicated or for when there is specific clinical concern despite a negative SPT result. A prospective study examining this however would provide clarification. There are training and cost implications in delivering a health surveillance programme of this nature, such as ensuring OH practitioners are sufficiently competent in conducting and interpreting SPT results. Practitioners should also be sufficiently competent in interpreting questionnaire responses. The interviewer-administered format allowed flexibility in eliciting further detail about responses, but it may not be practical to deliver the questionnaire on a wider scale in this fashion. One compromise could be to administer the questionnaire in self-completed format and advise face-to-face review for any responses that raise clinical concern. Such practices are commonly used in occupational health surveillance, but their sensitivity, specificity and predictive validity would need to be quantified.

8.2. Relationships between SPT and Specific IgE Tests

The fair to poor concordance between the SPT and IgE blood tests performed in this study for the fungal compost components merit discussion. The findings are in contrast to several other studies in which higher values of concordance between SPTs and specific IgE has been documented. Two studies recorded concordance at 85-95% depending on the allergen tested, although different specific IgE measurement techniques have been used (Bousquet et al 1990; Crobach et al 1998). Calabria et al 2009 compared serum specific IgE results with SPT results for 53 inhalant antigens in individuals with chronic rhinitis reporting an overall concordance of 80.6%. Nonetheless, in a study across 13 allergy centres of 168 individuals thought to be exposed to moulds or suffer from mould-related respiratory symptoms, concordance values between SPTs and specific IgE results were much lower at 40-50%, 30-42% and 63-67% for *A. fumigatus, C. herbarum and A. alternata respectively,* with findings varying according to different SPT manufacturers (Kespohl et al 2016). These were calculated using a 1.5mm cut-off and specific IgE greater than or equal to 0.35kU/L. It was also noted that sensitisation was more frequently detected by SPT than specific IgE. Other work has demonstrated similarly variable correlations (r=0.4-0.7) between SPT and RAST for cat, dog and perennial rye aeroallergens (Witteman et al 1996). The authors postulated that high total IgE may dampen the SPT responses through competition inhibition of specific IgE in binding to receptors on basophils. The total IgE concentrations of workers in this study were not measured. Further suggested patient-dependent factors to explain these findings included variability in mast cell degeneration and differences in antibody affinity. Others have suggested that the higher prevalence of sensitisation detected by SPT may be due to escape from detection in serum if only present at low concentrations in the allergenic extract (van der Zee et al 1988). It should be noted that these tests measure the presence of IgE antibodies in different ways. In the case of the SPT, when an antigen is introduced on to the skin, specific IgE bound to the surface of mast cells are cross-linked and degranulate which leads to the release of histamine and other inflammatory mediators mimicking the *in vitro* response (Heinzerling et al 2013). Specific IgE blood tests however measure circulating antibodies in the blood to the allergen concerned. A Swiss study of over 8000 individuals demonstrated that SPTs had a higher positive predictive value in determining clinical allergy for respiratory disease than total IgE concentrations and a variant of ImmunoCAP known as Phadiatop™. This led the authors to recommend SPTs as the optimal method for diagnosing sensitisation related to allergic respiratory disease (Tschopp et al 1998). Other explanations for the degree of discordance seen in this study include user technique in administering the SPT, stability of the antigens and differences in protein content across solutions. Indeed, the presence of different antigen concentrations may also be relevant, and variations in SPT results for the same allergen extract across different manufacturers has been reported (Heinzerling et al 2013). One study noted marked differences in allergen concentrations across four manufacturers (Kespohl et al 2016). Unfortunately, I was unable to find out which specific antigen sequences were used in the SPTs from the manufacturer and specific IgE tests in this study. In this study, I used a cut-off of 3mm diameter to establish whether a reaction to an allergen was positive in conjunction with a positive histamine control. It is notable however that a variety of cut-offs have been applied in other studies also including >0mm, >1.5mm, >4mm and >5mm (Bousquet et al 2007; Kespohl et al 2016; Merget et al 2017).

Nonetheless, this study highlights the importance of conducting SPTs, and it is evident that studies that do not use SPTs, such as those that solely measure serum specific IgE, may miss sensitised individuals. Sensitisation to *Aspergillus fumigatus* in the composting industry is common, yet its predictive value in identifying illness is unknown. Whilst studies linking specific bioaerosol exposures to symptoms are needed, research examining the prevalence of sensitisation and symptoms at entry and leaving the industry, as well as in those that remain in work would shed light on the predictive value of tests identifying sensitised workers at risk of developing illness.

8.3. Irritant Symptoms

The relationship between allergic rhino-conjunctivitis and allergic asthma is well established (Simons 1999), but less is known however about the relationship between non-allergic rhino-conjunctivitis and lower airways disease. In this study, there were a number of non-sensitised workers that reported symptoms of mucous membrane irritation affecting the eyes and nasal passages. A small number of these also complained of lower airways symptoms, such as cough or shortness of breath who were non-smokers. From this cross-sectional study however, it is not possible to establish cause-and-effect, such that it is unclear whether the reported symptoms are in any way related.

Logically, one may surmise that 'irritation' of the upper airways may eventually lead to or be associated with irritation of the lungs. Previous work has investigated this phenomenon, establishing a strong association between chronic bronchitis and work-related eye irritation (odds ratio 38.6) and nasal irritation (odds ratio 25.0) after excluding allergic asthmatics from the analysis (Hoffmeyer et al 2014). The implications of this finding mirror those described earlier relating to how health surveillance should be delivered and when action to reduce exposure should be recommended in light of clinical findings. Of note however is that whilst attention has been paid to the risk of developing allergic respiratory disease in the composting literature, the relevance of irritant and toxic symptoms should not be overlooked.

8.4 Other Data

Symptoms and sensitisation according to exposure status

No differences were found in rates of upper and lower airways complaints amongst compost operatives and those working predominantly on-site as opposed to those with mixed duties or purely office-based duties. Those with mixed duties predominantly conducted tasks such as sampling and quality control and thus were on-site frequently but for short periods. The study may also have been underpowered to detect a difference between these groups.

Years in industry

Workers that had spent more than 10 years working in the industry had a significantly higher prevalence of eye symptoms than those in the field less than 5 years. Further work should examine the predictive validity of such findings in diagnosing and developing occupational illnesses which might include chronic bronchitis, COPD, occupational asthma and rarer conditions such as EAA, ODTS and ABPA. No differences in symptoms were seen in symptoms according to *Aspergillus* sensitisation status in those compost workers who had been in the industry more than 10 years, but the study was not powered to detect this difference. Prospective cohort studies can provide valuable data to inform the relevance of, for example, immune surveillance in the occupational management of compost workers.

Site Type

My results suggest that there are no differences in the prevalence of symptoms between those working in open-windrow and IVC sites, but once again it should be noted that the study may not have been sufficiently powered to detect any differences. As the industry moves forward, this remains an important area of study not least because the trend is towards developing more indoor composting sites. Symptoms from exposure to microbial VOCs and irritant gases merit further consideration (Tolvanen et al 2005, Persoons et al 2010). There were two cases in this study in which I suspected the worker's symptoms may have been due to gas exposures as opposed to bioaerosol emissions given the patterns described and the resulting medical intervention.

Asthma and Immunosuppression

Asthmatic workers were more likely to be sensitised to *Aspergillus fumigatus* in the study. Further work may consider examining this issue in more detail as the finding may have significant implications for occupational health practice in this area. There may be a need for closer health surveillance for asthmatics working in the industry should sensitisation predict symptoms. Accordingly, there may be implications for workers' tenure in such cases and legal ramifications should sensitisation be considered a personal injury which has occurred through work. Asthmatics may need to be advised of an additional risk of occupational illness and be removed/restricted from high exposure tasks.

The use of respiratory protective equipment and health surveillance practices

My observations of these practices indicate that there is uncertainty in the industry as to how best reduce bioaerosol exposure to workers. In some cases, managers cited difficulty in determining what a 'safe' level of bioaerosol exposure would be in the absence of occupational exposure limits and described the challenges of eliminating exposures for workers. RPE use was mixed, varying from simple masks and FFP3 masks to air-fed respirators with helmets. The frequency at which cabs and filtered were inspected and maintained also varied. The practicalities of using RPE for long periods should be assessed further, particularly related to discomfort and vision impairment of visors in hot, humid environments. Masks should be face-fitted to afford the appropriate protection factor, and simple cloth or FFP3 masks may be insufficient for high-exposure tasks. Given the comments regarding thermal discomfort and visual impairment from RPE, there may be grounds for work to develop more amenable RPE equipment for workers in this industry.

8.5. Further Work

This thesis has shed light on several important issues about the health of UK industrial compost workers, but many unanswered questions remain. As highlighted in the literature review, existing research in this area has been geared toward understanding exposures in these workers such as concentrations of specific bioaerosol components (fungal, bacterial, endotoxin); particle sizes; patterns and durations of exposure. Far less attention has been paid to health.

Exposure-Response Studies

Most of the studies examining the health effects of bioaerosol exposure from compost are cross-sectional in nature or have been presented in the form of case reports. The main observed effects include an increased prevalence of upper airways and ocular mucous membrane complaints, lower airways disease as well as gastrointestinal and dermal symptoms. A few studies have also examined the subclinical effects of bioaerosol exposure (Douwes et al 2000; Sigsgaard et al 2000; Wouters et al 2002; Heldal et al 2003; Muller et al 2006). The most significant longitudinal study in this field is that of current and former compost workers in Germany from which a number of publications have been produced (Bunger et al 2007; Hoffmeyer et al 2014; Van Kampen et al 2016). These identify a persistence of lower airways complaints in some individuals that have left the profession and ceased exposure, in both allergic and non-allergic individuals. Nonetheless, there is a need for more high-quality longitudinal controlled studies to build on such findings, particularly if causal inferences about exposure are to be made.

Future work should examine the relationship between dust levels (total, inhalable and respirable) and concentrations of bioaerosols such as fungi, bacteria and endotoxin.

This would be of practical benefit, since it is possible that one or more may act as surrogates for others. Measurement of dust particles in general is less resource-intensive than the other components. Additionally, there are established workplace measurement thresholds for short-term (15 minutes) and long-term (8 hours) exposure which could be used to develop occupational exposure limits if dust measurements can act as a surrogate for other bioaerosol components. Douwes et al (2000) demonstrated a moderate correlation between endotoxin and β-glucan in two surveys of a single composting plant conducted 1 year apart.

Despite the clear benefits to the industry in establishing occupational standards, characterising exposure-response relationships may be challenging. A 2015 expert review of existing exposure-response data regarding the health effects of bioaerosols concluded that there were no studies of suitable quality from which to derive occupational exposure limits, and that work in this area was urgently needed (Walser et al 2015). To understand this further, one would need to be able to link specific health effects to the types of exposures encountered at the time the symptoms develop. Understanding the relationships between exposure and symptoms would be best achieved using a longitudinal workplace study following a group of workers already known to experience work-related symptoms. Symptoms would need to be recorded, perhaps using a workplace diary, and for further validation a subclinical measure of response would be recommended such nasal, salivary, lung or blood inflammatory markers.

Although limits for endotoxin concentration exist in the Netherlands, whether these are appropriate for the variety of bioaerosol exposures encountered by compost workers is uncertain. For instance, 50 workers in this study had clinically detectable, but not 'clinically-significant', levels of specific IgG to *Actinomycetes spp.* The long-term implications of this are not widely understood, but a cross-sectional study by Heldal et al 2015 indicated an association between cough in compost workers and *Actinomycetes* spore concentrations. Another uncertainty is the relevance of elevated specific IgG to *A.fumigatus* in day-to-day occupational health practice, and how to interpret results should this be measured. One study has indicated that IgG levels in workers can be used as a surrogate marker for exposure (Eduard 1995). As described earlier, levels may be raised in cases of EAA. It is unclear whether specific IgG has a role in assessing exposure-response relationships.

Assessments of exposures and health symptoms in other countries may also be prudent. It is possible that there is variation in the understanding of the potential adverse health effects of bioaerosols and application of appropriate safety measures both within and across different areas of the world. Even in countries with well-developed regulatory standards, exposures for workers in smaller composting facilities with less rigorous industrial practices could be higher. Different bioaerosol and environmental aero-allergen distributions may well influence the types of results found in different settings (Heinzerling et al 2013). This study only provided a brief overview of RPE use and health surveillance practices in the UK composting industry, mainly based on personal observation, with the exception of the quality of spirometry data which was examined in greater detail. There is scope to better understand the factors influencing compliance with RPE amongst workers which could be examined with qualitative or mixed-method approaches. This might include issues about RPE acceptability to workers such as comfort or fit; levels of awareness about the importance of RPE or attitudes towards its use. Should discomfort or other factors such as impaired vision be significant barriers to the use of RPE; there may be ways to redesign them to tackle these problems. As already discussed, the varying approaches to health surveillance seen in this study suggest a need for professional guidance in this area.

Health Studies

The need to establish the predictive value of tests for sensitisation has been discussed earlier. Such a study would need to establish symptoms and sensitisation at the point of entry and exit from the profession should they leave due to ill-health, as well as in those who remain in work. It is my belief that the use of specific IgE alone may miss sensitised individuals and underlines the importance of including skin prick tests should such a study be performed.

Other work in this area may examine differences in symptoms, as well as exposures, between outdoor windrow and indoor sites such as IVC and anaerobic digestion (AD) facilities, which are currently not well-characterised. Of note, I was informed by one of the safety managers in this study that no studies of health symptoms or bioaerosol exposures have been conducted in AD sites in the UK. Other exposures such as gases, VOCs, terpenes and biological enzymes may have a role in inducing ill-health amongst compost workers, and this should be explored.

Further work may also compare the epidemiology of symptoms and allergy in other industries in which bioaerosol exposure is known to occur. Such information may be useful in helping regulators and those concerned with health and safety to prioritise their efforts and resources. A study of 1032 workers in the United Kingdom across 9 industries in which organic dust exposure is known to occur reported an increasing prevalence of respiratory symptoms with higher bioaerosol exposure, with the strongest association seen for endotoxin (Simpson et al 1998). Other workers which may be exposed to bioaerosol include those handling mouldy hay and animal feeds; working in animal sheds, stables and picking mushrooms (Swan et al 2003). Symptoms of mucous membrane irritation, rhinitis, asthma, ODTS, bronchitis and EAA have all been previously reported in the agriculture sector (Von Essen et al 1999; Kirkhorn & Garry 2000). A higher prevalence of symptoms suggestive of chronic bronchitis were found in a Ukranian study of 240 animal feed workers as compared to controls (Kuchuk et al 2003). Consistent methods to assess exposure, record symptoms and detect allergy would improve the validity, reliability and generalisability of results.

The small number of immunocompromised and medically vulnerable compost workers in this study precluded any meaningful statistical analysis of sensitisation or symptoms with their immunocompetent counterparts. Specific risk factors for invasive Aspergillus disease include cystic fibrosis, prolonged neutropenia either due to underlying medical diseases such as cancer or secondary to immunotherapy; and those with organ transplantations. Those with severe asthma may also be at greater risk of occupational illness. Further work should clarify whether these workers can be safely employed in tasks with high exposure to bioaerosol in compost.

8.6. Reflections

This study is one of the largest to have examined the health of workers in the compost industry and with exception of one other (Gladding et al 2003), the first in the United Kingdom. The strengths and limitations of the study, as well as areas for further research have been discussed in detail. Whilst I have produced some pertinent findings, there is still a long way to go before there is sufficient evidence to support causal associations to inform occupational exposure limits. This, for me, should be the primary goal for those researching this field.

Both sensitised and non-sensitised individuals appear to be at risk of developing occupational illness related to bioaerosol exposure from compost. At this time, there is no convincing evidence to suggest prioritising the surveillance of one group over another but where medical surveillance may help is identifying which workers fit into each category. This in conjunction with a fuller understanding of how disease patterns develop in such workers when exposed to compost can inform their occupational management. For instance, should sensitised workers be immediately restricted from high-exposure roles? The findings from this study do not suggest that such workers are specifically at an increased risk of developing occupational illness, but the cross-sectional approach limits the inferences which can be drawn. In those workers with non-allergic pathology; at what point should modifications be made to their role and how often should they undergo medical surveillance? Should they be found alternative work when they develop lower airways symptoms, abnormal spirometry or when they develop rhino-conjunctivitis. Given the frequency of complaints of rhinitis and conjunctivitis observed in this and other studies, removing workers that suffer from upper airways or ocular irritation could have a significant impact for the companies concerned, but opportunities for modified or alternative work may exist, particularly in larger employers. A pragmatic approach may be necessary, in conjunction with appropriate RPE.

The predictive validity of the health questionnaire used in this study should be examined. I believe it is sufficiently practical to administer through existing OH service provision. Understanding the relationship between exposure and symptoms in other green waste and waste processing fields remains of interest. For example, there are no studies of AD sites in the UK, and data regarding VOC and irritant gases are sparse. It may be that different exposure limits may apply for different settings, rather than a 'one-size-fits-all' approach for windrow, IVC and AD sites.

This project posed several new challenges in that it was the first in which I had negotiated the involvement of industrial companies and trade unions. The sensitivities of working with these groups such as ensuring minimal losses to productivity whilst administering the study and dealing with the concerns of management about the possible effect of the findings on their workforce are two such examples. These skills are important for occupational physicians to have since for many, working effectively with businesses and industries are a core part of practice. My understanding of the dynamics of conducting research through UK government organisations and regulatory bodies has also improved, and during my time at the Health and Safety Laboratory I have gained a body of knowledge through spending time with national and international experts in this field.

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Appendices

Appendix A

Recycling Sector	*Hazards to Health*	*Reported Clinical & Biological Health Effects*	*Possible health surveillance to consider if occupational illness is identified, controls are insufficient or their effectiveness uncertain*
Metals, batteries, cables, wires and catalytic converters	Inorganic dust, lead, other heavy metals to include Hg and Pt, noise, radioactive materials, dioxins, furans	Pb poisoning in lead-acid battery; raised urinary Hg in alkaline battery workers	BM for Pb, Hg and other heavy metals as appropriate to the metals being extracted, audiometry for NIHL
Glass to include cathode ray tubes	Noise, bioaerosols	MMI, Raised blood Pb	Health questionnaire*, BM for lead, audiometry for NIHL
Fluorescent lights	Inorganic dust, metal fume, mercury, lead, yttrium	Hg & Pb poisoning, MGN and nephrotic syndrome	BM for Hg and Pb
Landfill	Inorganic dust, bioaerosols, asbestos, gases	MMI, respiratory, dermatological and gastro-intestinal symptoms	Health questionnaire*

Textiles	Organic dust, bioaerosols	MMI, respiratory symptoms, abnormal lung function tests, byssinosis, COPD, OA	Health questionnaire*, serial peak flow diary, longitudinal spirometry
Wood, chipboard & bark chippings	Dust, bioaerosols	Acute pulmonary aspergillosis from bark chippings; OA from burning wood; MMI, OA, EAA, COPD from manufacturing with wood.	Health questionnaire*, serial peak flow diary, longitudinal spirometry
Medical waste	Sharps, blood borne viruses, radioactive materials, heavy metals in incinerator ash	Seroconversion from sharps injury	Immunisation to hepatitis B; follow-up for seroconversion; post exposure prophylaxis
Paper	Organic contamination, bioaerosols	MMI, OA, sensitisation to storage mites	Health questionnaire*, serial peak flow diary
Waste electronic electrical equipment (WEEE)	Heavy manual handling, inorganic dust, PAHs, heavy metals, dioxins, furans, brominated diphenyl ethers (flame retardants)	Respiratory symptoms, abnormal lung function, adverse neonatal outcomes, chromosomal aberrations, argyria	Health questionnaire*, BM as appropriate for the metals being extracted.

Table 32: Hazards, Health Effects and Health Surveillance to be considered by Sector

The table summarises the main exposures (second column) and health hazards (third column) associated with different waste and recycling sectors. Suggestions are provided in the final column should risk assessments indicate a need for health surveillance, controls to the exposure(s) be insufficient or there are suspected/established cases of occupational disease related to the exposures concerned.

*Abbreviations: VOCs = volatile organic compounds, PAH = polycyclic aromatic hydrocarbons, MMI = mucosal membrane irritation, OA = occupational asthma, EAA = extrinsic allergic alveolitis (hypersensitivity pneumonitis), ODTS = organic dust toxic syndrome, ABPA = allergic bronchopulmonary aspergillosis, SPTs = skin prick tests, BM = biological monitoring, Pb = lead, Hg = mercury, Ag = silver, Pt = platinum, MGN = membranous glomerulonephritis, COPD = chronic obstructive pulmonary disease, NIHL = noise-induced hearing loss *Health Questionnaire should be tailored to relevant hazards, exposures and known health effects*

Appendix B

Project Questionnaire

The Health of Compost Workers

As you are aware Dr.Subhashis Basu is conducting a study to assess the health effects of working with waste. We would be grateful if you would kindly complete this questionnaire which should take no more than 10 minutes to allow us to do this.

There is no obligation to take part in this study and your involvement is entirely voluntary. Your responses to the questionnaire and results from the blood and skin prick test are anonymous and will not be relayed to management. With your permission however, we can pass the results of the tests to your GP should you wish.

His contact email is subhashis.basu@hsl.gsi.gov.uk. Alternatively, you can contact Dr.Jon Poole at the Health and Safety Laboratory, Buxton at jon.poole@hsl.gsi.gov.uk.

Have you seen the worker information sheet and the explanation of the use of your data? Yes/No

If you agree to take part, please sign the consent form

Section A: Personal Details

First Name	Surname
Date of Birth	[redacted]
Home Address	M ☐ Fen ☐
Height	Weight
GP Name and Address (so that we can write to them).	

Section B: Job History

<table>
<tr><td colspan="2">Current Job:</td><td colspan="2">Site</td></tr>
<tr><td></td><td rowspan="2">Years</td><td colspan="2" rowspan="2">Months</td></tr>
<tr><td>Time worked in current role</td></tr>
<tr><td colspan="4">Please tick if you work at or within 10 meters any of the following processes during your working day (if they apply)

Sorting of waste

Shredding

Turning

Screening</td></tr>
<tr><td>Do you walk within 10 meters of open compost during your working day?</td><td colspan="3">Yes ☐

No ☐</td></tr>
<tr><td>How long have you previously worked with waste as part of your job?</td><td>Years</td><td colspan="2">Months</td></tr>
</table>

Section C: Respiratory Protection Equipment

Q		Hours	Minutes
1	On average, how many hours a day do you work in an area with local exhaust ventilation?		
2	On average, how many hours a day do you work in an area in a filtered cab?		
3	On average, how many hours a day do you wear respiratory protective equipment (RPE) on site?		
4	Which of the following types of RPE do you wear at work?	**Yes and which task?**	**No**
	Disposable Half-Mask Respirator  		
	Simple Cloth or Fabric Face Mask 		

	Half Mask Filter respirator  		
	Full-face respirator 		
	Air Fed Helmet 		
3	If not, why do you not wear RPE:		

Section D: Medical History

Q			
1	Have you ever been diagnosed by a doctor with any of the following breathing problems?	**Yes**	**No**
	Asthma?		
	COPD (a long-term lung problem)?*		
	Another breathing problem such as cystic fibrosis, bronchitis or bronchietasis? If yes please specify:		
2	Have you ever been diagnosed by a doctor with?		
	Eczema?		
	Hay Fever?		
	Any form of allergy? (e.g. peanut, egg etc..)		
3	Do you:	**Yes**	**No**
	Take medicines such as inhalers, aerosols or tablets for asthma?		

	Smoke outside of work?		
	How many cigarettes or roll-ups do you smoke per day?		
	For how many years have you smoked?		
	If you do not smoke now, have you smoked in the past?		

CHEST TIGHTNESS				
Q	In the last 12 months	**Yes**	**No**	
1	Has your chest become tight?			
2	Have you been woken up because of chest tightness?			
3	Do you only get chest tightness with colds?			
4	Is your chest tightness better, the same or worse away from work?	**Better**	**Same**	**Worse**
5	Is your chest tightness better, the same or worse on holiday?	**Better**	**Same**	**Worse**
SHORTNESS OF BREATH				
Q	In the last 12 months	**Yes**	**No**	

6	Have you had shortness of breath when walking or at rest?			
7	Have you been woken up because of shortness of breath?			
8	Do you only get shortness of breath with colds?			
9	Is your shortness of breath better, the same or worse away from work?	**Better**	**Same**	**Worse**
10	Is your shortness of breath better, the same or worse away on holiday?	**Better**	**Same**	**Worse**
WHEEZE (make a whistling noise when you breathe out)				
Q	In the last 12 months	**Yes**	**No**	
10	Have you ever had wheezing or whistling in your chest?			
11	Have you been woken up with wheezing or whistling in your chest?			
12	Do you only get wheezing/ chest whistling with colds?			
13	Is your wheezing/whistling better, the same or worse away from work?	**Better**	**Same**	**Worse**
14	Is your wheezing/whistling better, the same or worse on holiday?	**Better**	**Same**	**Worse**
COUGH				
Q	In the last 12 months	**Yes**	**No**	
15	Have you had a cough that has kept you awake at night?			

16	Do you usually cough first thing in the morning in winter?			
17	Do you usually cough at other times of the day or night in the winter?			
18	Do you usually bring up any phlegm from the chest when you cough?			
19	Do you cough like this on most days for as much as three months out of a year?			
20	Have you coughed-up any green plugs or brown strings			
21	Is your cough better, the same or worse away from work?	**Better**	**Same**	**Worse**
22	Is your cough better, the same or worse on holiday?	**Better**	**Same**	**Worse**
	General Wellbeing			
Q	In the last 12 months have you had unexplained	**Yes**	**No**	
23	Weight Loss?			
24	Flu-Like symptoms?			
25	Fevers?			
26	Shivering?			
27	Joint or muscle aches?			
28	General feelings of being unwell?			
29	If yes to any of Q24-28, how long after the start of the working week did these occur?	**Number of Days**		
30	How long do the symptoms usually last?			

EYE IRRITATION					
Q		Yes		No	
31	Do you suffer from irritation such as pricking, itching, burning, dryness, watering, soreness or stinging of the eyes?				
32	Is the eye irritation worse in any particular season of the year?	**Winter**	**Spring**	**Summer**	**Autumn**
33	Is/was your eye irritation better, the same or worse away from work?	**Better**		**Same**	**Worse**
34	Is/was your eye irritation better, the same or worse on holiday?	**Better**		**Same**	**Worse**
NOSE IRRITATION					
Q		Yes		No	
35	Apart from when you have a cold, do you ever suffer from irritation of the nose such as pricking, itching, burning or a runny, dry or blocked nose?				
36	Is the nose irritation worse in any particular season of the year?	**Winter**	**Spring**	**Summer**	**Autumn**
37	Is your nose irritation better, the same or worse away from work?	**Better**		**Same**	**Worse**
38	Is your nose irritation better, the same or worse on holiday?	**Better**		**Same**	**Worse**

RASH				
Q		Yes	No	
39	Do you have or have you ever had a rash that you attribute to work?			
40	Does your rash get better, stay the same or get worse away from work?	**Better**	**Same**	**Worse**
41	Does your rash get better, stay the same or get worse on holiday?	**Better**	**Same**	**Worse**
[redacted]		**Yes**	**No**	
42	Do you have any other medical condition for which you regularly see a doctor?			
43	What are these other medical conditions? *(ask about immunosuppression)			
44	Have you been prescribed any regular medications for your medical condition(s)?			
45	What are these medications?			

THANK YOU FOR COMPLETING THIS QUESTIONNAIRE, PLEASE WRITE DOWN ANY COMMENTS YOU MAY WISH TO ADD BELOW:

Notes for Researcher

A) Worker Code Number:

B) SPT Results:

	Wheal	Flare	P/N consider Dermatographism
Aspergillus			
Cladosporium			
Alternaria			
HDM			
Tree			
Grass			
Positive			
Negative			

C) Respiratory-Related Absences in last 5 years:

Appendix C

VOLUNTEER CONSENT FORM

The participant should initial each box in the right-hand column and then sign 1 to 3 below

I have read the information sheet	
I consent to participating in this research	
I understand that inclusion in this study is voluntary and I am free to withdraw at any time	
I agree to the research doctors using my results in an anonymised way so that I am not identifiable	
I understand that should I become incapacitated and cannot continue to participate in this study, the researchers will destroy my records and blood sample	
I agree to complete a medical questionnaire and give permission for a study doctor to perform skin prick tests and take a blood sample from me	
I give permission for my GP to be informed about my participation in the study and for them to be informed about any positive skin or blood test results relevant to my clinical care	
I give permission for the study doctor to review my sickness absence records	
I consent to the study doctor contacting the company's Occupational Health provider to review my breathing tests. Should results be unavailable, I agree to perform a breathing test	

NAME IN BLOCK CAPITALS:________________________________

Date:__________________

Signed ....

The study has been cleared to proceed by an NHS Research Ethics Committee. If you have any concerns over the conduct of the study, you may contact the National Research Ethics Service (NRES) directly (http:www.nres.npsa.nhs.uk/contacts).

Appendix D

Participant Information Sheet

You are invited to join in a research project called *The Health of Compost Workers* to look at whether employees working in the composting industry are at increased risk of developing breathing problems. Before you decide whether you wish to participate, please read the following information which explains why we are doing the study. Participation is entirely voluntary.

Purpose of the Study

It is thought that because of inhaling bacteria and fungi in the air compost workers may be at a greater risk of developing breathing problems. We would like to find out whether this is the case.

What is involved?

If you agree to take part, we will visit your workplace during your normal working hours with the agreement of your employer. The whole process will last about 30 minutes.

We will begin by asking you to fill out a short simple questionnaire about your health and things that may affect your chest such as smoking and previous medical problems.

We also ask your permission to let us see your sickness absence records for the previous two years to see if you have been off work because of any chest complaints, and the results of any breathing tests that you may have had done by the company's Occupational Health service. Should these results be unavailable, we will ask you to blow into a small tube attached to a machine so that we can measure your breathing.

In addition, we would like to take a small sample of blood from you of 10mls (2 teaspoons worth). This may cause slight discomfort at the time but will quickly settle. The blood test is to detect allergy in the blood that will allow the study team to see who may be at risk of developing breathing problems.

The study doctor will also ask to test the reaction of your skin to some fungi contained within the compost. This involves placing a small amount (1ml) of the diluted fungus into the skin of your forearm using a thin needle and seeing if a small rash develops. We would then use a ruler to measure the size of the rash fifteen minutes later. The purpose of this is to determine whether you have allergy in the skin and may be at risk of developing breathing problems.

We will also test your skin reaction to house dust mite, grass pollen, tree, water and histamine at the same time to see if you are allergic to any of these agents. This will help us to interpret the results of the tests for the fungus.

The procedure, called a skin prick test, is commonly done all over the country in many hospitals. It will be performed by a doctor trained in the test. The most common side-effect is that of temporary itching and there is a very small risk of skin infection. The test is extremely safe and not painful. All relevant first-aid treatment will be brought by the study doctor.

How do I prepare?

We request that you do not take any antihistamine medication during the 5 days prior to your skin prick test. These medications include:

Fexofenadine
Ebastine
Promethazine
Cetirizine
Clemastatine
Hydroxyzine
Promethazine
Loratadine

If you are unable to do this, please inform the study doctor when he sees you at your place of work prior to the skin prick test.

Do I have to take part?

No, the study is voluntary, and you may withdraw at any time without obligation.

What are the possible benefits of taking part?

The skin test and blood test will identify whether you may be at risk of developing chest and breathing problems currently or in the future due to working with compost. The results of the test will be reported back to you personally, but will not be reported back to your employer. We will tell them how many employees are allergic to the fungus but not where they work. If you wish to tell your employer, that is your choice.

You can discuss the results with us or your general practitioner. We will advise on the implications of any results. The overall findings from the study may also help benefit other workers in the composting industry who may be at risk of developing breathing problems as a result of their work.

What are the possible risks of taking part?

Both tests are extremely safe and are commonly performed by doctors. The main risks are bruising following the blood test, and itchiness due to a rash following the skin test.

Will my taking part be confidential?

Yes, no one else other than the study team will know about your results unless you wish them too. All information will be treated in the strictest confidence. Your test results will be stored securely within the Health and Safety Laboratory, Buxton, to which only the study doctors will have access. Results will be communicated to you in writing, of which your employer will not be aware. With your consent, we will write to your GP to inform them of your participation in the study.

What will happen to the results of the study?

The results of the study will be published in a report in a scientific journal. Your own results will not be identifiable from these reports.

Who is organising and funding the study?

The Health and Safety Laboratory has funded the study

Who has reviewed the study?

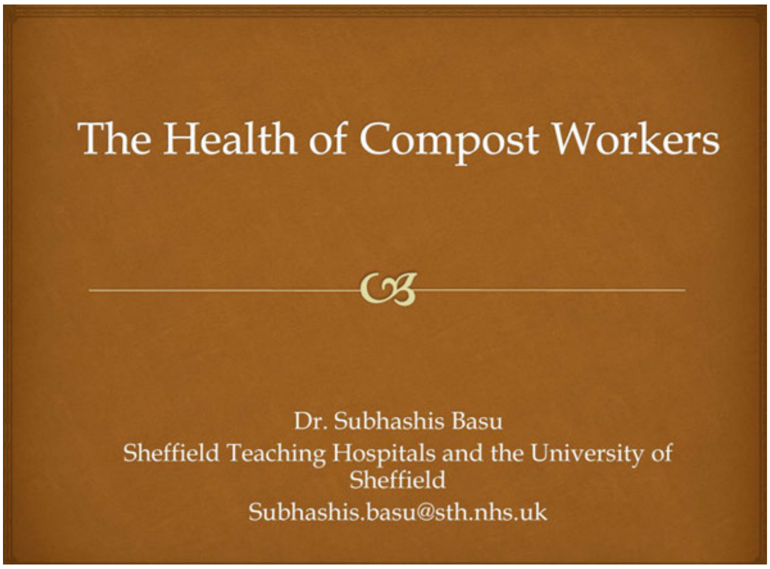
Consent to undertake the study has been sought from the North West NHS Ethics Committee.

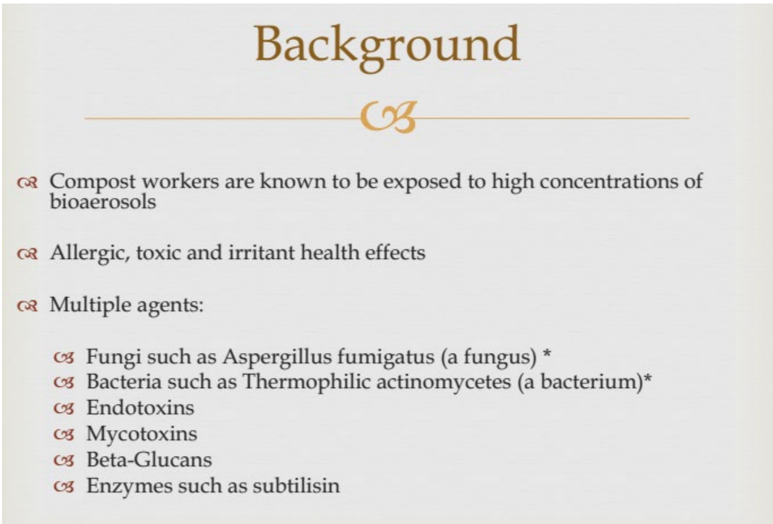
Contact for Further Information

If you require further details or advice regarding participation please contact Dr Subhashis Basu subhashis.basu@hsl.gsi.gov.uk or Jon Poole 01298 218452, jon.poole@hsl.gsi.gov.uk, HSL Harpur Hill Buxton, SK17 9JN.

Appendix E

COMPANY PRESENTATION





letsrecycle.com

Health expert warns of bioaerosol risk

By Tom Goulding

- **A health expert has warned that waste companies need to be more aware of the health risk of bioaerosols to their workers, at a health and safety conference in Stockport yesterday (September 27).**
- Speaking during the fourth annual Health and Safety in Waste Management conference organised by letsrecycle.com, Dr Peter Sykes, principal lecturer at Cardiff Metropolitan University, urged caution from operators in the absence of specific legislation and guidance on the hazard.

Spectrum of Disease

Common

- None
- Allergic Rhinitis/ Rhinoconjunctivitis
  - Nose, eye, or throat irritation mucous membrane irritation
- Allergic/ Irritant Asthma
- Extrinsic Allergic Alveolitis
- Organic Dust Toxic Syndrome
- Allergic bronchopulmonary mycoses

Rare

At Risk Workers

- Highly exposed workers
- Those with pre-existing lung conditions
- Those who become sensitised (an early stage of allergy) to organisms in the compost
  - Blood IgG or IgE
  - Skin Prick
  - Atopics
- Those with underlying health problems
  - health conditions weakening the immune system or the airways
  - medications weakening the immune system eg steroids

Gardening can seriously damage your health

Katherine Russell, Carl Broadbridge, Sebastian Murray, David Waghorn, Allan Mahoney

Lancet 2008; 371: 2056

Department of Microbiology (K Russell MBBS

In May, 2007, a 47-year-old man was admitted with a 1-week history of productive cough, pleuritic chest pain, increasing shortness of breath, fever, and myalgia. He

two sputum samples. On closer questioning, the patient's partner revealed that his symptoms had started less than 24 h after he had dispersed rotting tree and plant mulch

CASE REPORT

Allergic bronchopulmonary aspergillosis in garden waste (compost) collectors—occupational implications

C. J. M. Poole and M. Wong

Department of Occupational Health, Dudley & Walsall NHS Trust, Health Centre, Dudley DY1 1RN, UK

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A 5-year follow-up study on respiratory disorders and lung function in workers exposed to organic dust from composting plants

Jürgen Bünger · Bernhard Schappler-Scheele · Reinhard Hilgers · Ernst Hallier

Known Knowns

- **Background** Aspergillus concentrations of 10 cfu/m^3 - 400 cfu/m^3
- **Near** compost sites (within a kilometre)
  - Aspergillus - 10 to 10^4 cfu/m^3
  - Total Bacteria - 100 to 10^5 cfu/m^3
- **In** compost sites
  - Aspergillus 10^8 cfu/m^3 *
  - Total bacteria 10^7 cfu/m^3 *
  - Endotoxin 1 – 10^4 EU/m^3 *
  - Glucan up to 3400 ng/m^3 *

Known Unknowns

- **Seasonal & longitudinal variations in exposure**
- **Spectrum and prevalence of ill-health (one large German study, a few other smaller studies)**
- **Incidence of ill-health**
- **Rates of sensitisation to fungal/bacterial bioaerosols**
  - Do sensitised workers have higher rates of illness/ more likely to develop illness?
- **How to perform health surveillance**
  - Is a questionnaire enough?
  - What questions should be asked?
  - Should skin prick tests or blood tests be done to detect emerging allergy?
  - What combination of tests should be used?

Unknown Unknowns

- Other bioaerosols in compost & associated health effects – few quantitative studies
- Influence of changing trends in industry – shift towards closed processes
- Effectiveness of control measures – filtered cabs, RPE, others
- Longitudinal effects on lung function – one study suggests decline
- Where to set OELs
  - No established occupational exposure limits*
  - EA exposure limits are not health-based**

First Steps – Research Questions

- *Is the prevalence of work-related respiratory symptoms in the UK industrial composting workforce greater than in the general population?*
- *Are rates of sensitisation to fungal moulds and bacterial antigens commonly found in UK compost higher in the industrial workforce than general population controls?*
- *Is there a relationship between symptoms and sensitisation?*

Design and Methods

- Cross-Sectional
- Volunteers complete a respiratory health questionnaire to assess work-related illness developed by SB in conjunction with the industry
- Safe, minimally-invasive tests
  - Skin prick tests and blood test to *Aspergillus fumigatus, Cladosporium, Alternaria and Actinomycetes*
- SB spends 20 mins with each worker
  - 5 mins to explain and consent; 15 mins for tests
- For future work
  - *Aim to achieve equal numbers of open windrow and indoor compost workers*
  - *Aim to obtain equal groups of workers in high, medium and low (general population) exposure groups*

So far

- Ethical Approval
- Meetings with Trade Unions and Industry
- Industry Magazine and Website
- Several companies recruited
- Site Managers engaged

Implications and Risks

- *Frightening the workforce and management?*
  - Vast majority of workers will have no symptoms of occupational lung disease
  - In exceptional cases - we would identify an individual that may wish to leave their job.
  - For at-risk workers, one strategy would be to increase the workplace controls for those workers
  - A worker who knows they are sensitised or vulnerable may be more inclined to follow safe working procedures.
- *Risks to Participants?*
  - Minimal from skin prick and blood tests (pain, itching, fainting)
  - SB is trained to perform both tests
  - SB will carry necessary emergency equipment with him and is trained to use it
  - Results will be kept password protected and anonymised on an IT network at HSL

Results so far

- 60 workers out of 62 invited. 3 declined blood tests
- Intended number 100-120 workers
- Most report symptoms of upper airways mucous membrane irritation
- 1 suspected case of EAA/ODTS
- No cases of ABPA
- Low rates of sickness absence

Advice to Management and OH Providers

- We will discuss the implications of positive results in general terms with management before results are communicated to the workers

- We will provide advice/information on:
  - The number of workers who are sensitised to each fungus
  - Whether any workers have or may be at risk of developing occupational lung disease
  - Update advice regarding health surveillance for these workers
  - If we have sufficient data an analysis of serial breathing tests

Advice to the worker

- In all cases, we will explain the results by letter with telephone and e-mail contact details for the researchers.
  - Most workers will have negative results to microbial agents and/or positive results to control agents (house dust mite, grass and tree pollen)
  - Some will be sensitised to a micro-organism in compost but this is of no consequence (cf Farmer's lung)
  - A few will be sensitised to one or more microbial agents **and** are allergic, or immunosuppressed, or are medically vulnerable
  - A worker may be found with suspected occupational lung disease who will require specialist investigation.
  - No worker will be told to leave their job; they will be advised to discuss their results with their manager
  - A letter will be sent to the worker and their GP with their consent, with the results of their tests and explanation

What else would we like to know?

- Do any of the compost workers have an underlying illness or personal vulnerability which makes them susceptible to occupational lung disease?
- Do any of the compost workers have occupational lung disease? (analysis of serial spirometry)
- Are there differences in reported symptoms and rates of sensitisation according to open/closed processes and exposure status?
- What are the seasonal/longitudinal variations in exposure?
- Which bioaerosol(s) are the most significant predictors of illness?
- Do sensitised workers go on to develop occupational lung disease?
- How should health surveillance be done?
- Do the workplace controls need to be improved, if so where and how?

Thank you and any questions?

Appendix F

ETHICAL APPROVAL

Health Research Authority
National Research Ethics Service
NRES Committee Northwest – Greater Manchester West
3rd Floor
Barlow House
4 Minshull Street
Manchester
M1 3DZ

Telephone: 0161 625 7434

14 May 2014

Dr Subhashis Basu
Specialist Registrar in Occupational Medicine
Health and Safety Laboratory
Centre for Workplace Health
Health and Safety Laboratory
Buxton
SK17 9JN

Dear Dr Basu

Study title:	**Occupational illness, sensitisation to Aspergillus fumigatus and health surveillance for compost workers**
REC reference:	**14/NW/0188**
IRAS project ID:	**148617**

Thank you for your letter of 24 April 2014, responding to the Committee's request for further information on the above research and submitting revised documentation.

The further information has been considered on behalf of the Committee by the Chair.

We plan to publish your research summary wording for the above study on the HRA website, together with your contact details, unless you expressly withhold permission to do so. Publication will be no earlier than three months from the date of this favourable opinion letter. Should you wish to provide a substitute contact point, require further information, or wish to withhold permission to publish, please contact the REC Manager Anna Bannister, nrescommittee.northwest-gmwest@nhs.net.

Confirmation of ethical opinion

On behalf of the Committee, I am pleased to confirm a favourable ethical opinion for the above research on the basis described in the application form, protocol and supporting documentation as revised, subject to the conditions specified below.

Ethical review of research sites

NHS sites

The favourable opinion applies to all NHS sites taking part in the study, subject to management permission being obtained from the NHS/HSC R&D office prior to the start of the study (see "Conditions of the favourable opinion" below).

Conditions of the favourable opinion

The favourable opinion is subject to the following conditions being met prior to the start of the study.

Management permission or approval must be obtained from each host organisation prior to the start of the study at the site concerned.

Management permission ("R&D approval") should be sought from all NHS organisations involved in the study in accordance with NHS research governance arrangements.

Guidance on applying for NHS permission for research is available in the Integrated Research Application System or at http://www.rdforum.nhs.uk.

Where a NHS organisation's role in the study is limited to identifying and referring potential participants to research sites ("participant identification centre"), guidance should be sought from the R&D office on the information it requires to give permission for this activity.

For non-NHS sites, site management permission should be obtained in accordance with the procedures of the relevant host organisation.

Sponsors are not required to notify the Committee of approvals from host organisations

Registration of Clinical Trials

All clinical trials (defined as the first four categories on the IRAS filter page) must be registered on a publically accessible database within 6 weeks of recruitment of the first participant (for medical device studies, within the timeline determined by the current registration and publication trees).

There is no requirement to separately notify the REC but you should do so at the earliest opportunity e.g. when submitting an amendment. We will audit the registration details as part of the annual progress reporting process.

To ensure transparency in research, we strongly recommend that all research is registered but for non-clinical trials this is not currently mandatory.

If a sponsor wishes to contest the need for registration they should contact Catherine Blewett (catherineblewett@nhs.net), the HRA does not, however, expect exceptions to be made. Guidance on where to register is provided within IRAS.

It is the responsibility of the sponsor to ensure that all the conditions are complied with before the start of the study or its initiation at a particular site (as applicable).

Approved documents

The final list of documents reviewed and approved by the Committee is as follows:

Document	*Version*	*Date*
Investigator CV	Poole	
Investigator CV	Basu	
Participant Consent Form	3	02 May 2014
Participant Information Sheet	3	08 May 2014
Protocol	2	08 May 2014
Questionnaire: Medical Questionnaire	1	07 March 2014
REC application	3.5	12 March 2014

Response to Request for Further Information		24 April 2014

Statement of compliance

The Committee is constituted in accordance with the Governance Arrangements for Research Ethics Committees and complies fully with the Standard Operating Procedures for Research Ethics Committees in the UK.

After ethical review

Reporting requirements

The attached document *"After ethical review – guidance for researchers"* gives detailed guidance on reporting requirements for studies with a favourable opinion, including:

- Notifying substantial amendments
- Adding new sites and investigators
- Notification of serious breaches of the protocol
- Progress and safety reports
- Notifying the end of the study

The NRES website also provides guidance on these topics, which is updated in the light of changes in reporting requirements or procedures.

Feedback

You are invited to give your view of the service that you have received from the National Research Ethics Service and the application procedure. If you wish to make your views known please use the feedback form available on the website.

Further information is available at National Research Ethics Service website > After Review

14/NW/0188	Please quote this number on all correspondence

We are pleased to welcome researchers and R & D staff at our NRES committee members' training days – see details at http://www.hra.nhs.uk/hra-training/

With the Committee's best wishes for the success of this project.

Yours sincerely

[redacted]

Dr Lorraine Lighton (Chair)
Chair
Email:nrescommittee.northwets-gmwest@nhs.net

Enclosures: "After ethical review – guidance for researchers"

Copy to: *Dr Jon Poole*
Mr Simon Heller, Sheffield Teaching Hospitals NHS Foundation Trust

Appendix G

Publications

Occupational Medicine 2017;67:626–636
Advance Access publication 20 November 2017 doi:10.1093/occmed/kqx153

Systematic Review: Occupational illness in the waste and recycling sector

C. J. M. Poole[1,2] and S. Basu[1,2]

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Background The waste and recycling sector is a growing part of industry. Whether health surveillance is indicated and how it should be undertaken is unclear.

Aims To undertake a review of the literature to identify hazards to health, biological effects and occupational illnesses for workers in the sector.

Methods A systematic review of the published literature and two UK databases.

Results Rates of fatal, non-fatal injuries and self-reported work-related illness were found to be higher in the waste and recycling sector than in UK industry as a whole. There was an increased prevalence of respiratory, gastro-intestinal and skin complaints in workers exposed to compost relative to controls. They may also be at increased risk of extrinsic allergic alveolitis, allergic bronchopulmonary aspergillosis, occupational asthma and abnormalities of lung function. Workers involved with the recycling of batteries and cables may be at risk of lead poisoning and exposure to other heavy metals. There were case reports of mercury poisoning from the recycling of fluorescent lights. Cases of occupational asthma have been reported in association with wood and paper recycling. The recycling of e-waste may cause exposure to heavy metals and organic pollutants, such as polybrominated diphenyl ethers, dioxins and polyaromatic hydrocarbons, which have been associated with damage to DNA and adverse neonatal outcomes.

Conclusions Ill-health and adverse biological effects have been described in waste and recycling workers, but their true prevalence has probably not been captured. Targeted health surveillance may be required to assess exposure and to identify occupational illness.

Key words Biological monitoring; health surveillance; recycling; systematic review; waste.

Introduction

The waste and recycling sector is worth £12 billion per year to the UK economy. It employs 200 000 people and is growing at the rate of 3–4% per year. It is driven mainly by European Union directives that contain the target of 50% of all household waste to be recycled by 2020. The fatal and non-fatal injury rate and the self-reported work-related illness rate of workers in the sector is higher than the industrial average [1] with potential hazards to health that include heavy manual handling; bioaerosol (components of dust of biological origin such as bacteria and fungi) exposure from garden, domestic or food waste; and lead and mercury exposure from the recycling of batteries, fluorescent lights and electrical equipment.

Concern has been expressed by the Health and Safety Executive (HSE) about inadequate risk assessments, the weakness of workplace controls, inadequate washing facilities and a lack of appropriate risk-based health surveillance as part of a quality management process at inspected workplaces in the UK [2]. Some hazards are known, such as stooping and twisting while lifting and carrying heavy boxes of glass or paper or while loading sacks of refuse onto a wagon and are best controlled by limiting the weight of boxes or by substitution with wheelie bins.

Other hazards may be suspected, such as exposure to bioaerosols from biomass-fired power plants or on industrial composting sites where concentrations of bacteria and fungi up to 1000 times greater than in ambient air have been measured [3]. Bioaerosols may comprise living or dead organisms; spores; substances released from cell walls when they rupture such as endotoxins and beta-glucans; or substances produced by organisms such as exotoxins and mycotoxins. All of these may cause toxic, irritant or allergic effects.

To what extent exposure should be controlled is uncertain. While exposure limits of 10 mg/m^3 8-h time-weighted average exist for total inhalable dust, there are no limits for the constituents of bioaerosols mainly because of the difficulty of establishing a dose–response effect and safe levels of exposure, although a Dutch Expert Committee has recommended health-based limits of 10^4 cfu/m^3 for bacteria in air and 90 EU/m^3 (5 ng/m^3) for endotoxins [3].

Some hazards may not be appreciated, such as exposure to heavy metals from telephone cables or to dioxins and furans from electronic waste recycling, so workers may unwittingly be at risk of occupational illness especially in those countries with low labour costs and poor regulatory standards.

We carried out a systematic review of the world literature to identify known hazards to health, biological effects and occupational illnesses for workers employed in the waste and recycling sector, and conducted a review of pertinent cases referred to by two of the UK's national surveillance schemes.

Methods

The literature search was conducted using Web of Science, Medline, Embase, Health and Safety Science Abstracts, OSH Update, elibrary and Google Scholar. Original research papers and case reports published in peer-reviewed journals between 1995 and 2015 were identified. The search strategies were developed by the authors to link the categories of population (such as 'worker'), with the environment (such as 'waste'), health (such as 'alveolitis') and exposure (such as 'mycotoxin'). To illustrate this, the search strategy for composting, biomass and green waste is shown in Table S1, available as Supplementary data at *Occupational Medicine* Online.

The titles and abstracts were reviewed separately by both authors. Systematic reviews, observational studies and case studies relevant to exposure, biological effect or occupational illness were identified. The full paper of those in English was sought. Figure 1 shows how the papers on compost, municipal and hazardous waste were identified.

Searches were done for each type of hazard and then grouped into the following related activities: composting, municipal or domestic solid waste and toxic waste; metal, automotive, batteries, cables and wires; glass and fluorescent lights; landfill, textiles and wood; medical waste, paper and nappies; and waste electronic electrical equipment (WEEE).

As most sectors were associated with only a few papers, a narrative review was conducted for them. Given the large number of articles retrieved for the composting, municipal solid waste and toxic waste, a structured systematic review was undertaken for this sector using a Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) flowchart. The Scottish Intercollegiate Guidelines Network (SIGN) grading system was used for systematic and narrative literature reviews and for case reports. A modified version of the Newcastle-Ottawa Scale [4] (Table S2, available as Supplementary data at *Occupational Medicine* Online) was used to assess the quality of the observational studies, which would have otherwise been given a similar score under the SIGN grading system. Papers were rated independently by each author and any differences reconciled through discussion. The HSE's Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR) database was scrutinized for cases of work-related illness reported from the waste and recycling sector between 2005 and 2015. The Health and Occupational Research (THOR) network database of work-related illnesses held at the Centre for Occupational and Environmental Health, University of Manchester was also searched for reported cases in the waste and recycling sector. THOR includes the Occupational Physician Reporting Activity (OPRA 1996–2015), Surveillance of Work-Related and Occupational Respiratory Disease (SWORD 1989–2015), Occupational Skin Surveillance Scheme (EPIDERM 1993–2015), The Health and Occupational Research Network in General Practice (THOR-GP 2006–2015), Musculoskeletal Occupational Surveillance Scheme (MOSS 1999–2009), Surveillance of Stress and Mental Illness (SOSMI 1999–2009), Surveillance of Infectious Diseases at Work (SIDAW 1996–2015) and Occupational Surveillance Scheme for Audiological physicians (OSSA 1996–2015).

As this was a systematic review of already published material, ethical approval was not required.

Results

Five hundred and seventeen papers were identified in total.

In the composting, municipal solid waste and hazardous waste recycling sub-sector, 278 abstracts were reviewed, which included 34 reviews, 184 observational studies and 10 case reports. The rest consisted of non-clinical reports, papers that were duplicate or irrelevant, commentaries or conference abstracts. The main reported hazards were heavy manual handling, inorganic dust, bioaerosols, volatile organic compounds and incinerator emissions to include polycyclic aromatic hydrocarbons, heavy metals, dioxins and furans.

Several papers from around the world reported increased accident rates and musculoskeletal injuries in refuse workers compared with controls or the general working population, with injuries mainly affecting the hands, arms, back or shoulders. It was suggested that the use of two- or four-wheeled containers instead of sacks had given rise to more shoulder and arm injuries but fewer back injuries [34].

The highest exposures to bioaerosols and volatile organic compounds (mainly terpenoids and alcohols) were found in sorting stations during the turning, shredding or screening of compost or biomass. Maximum concentrations of total micro-organisms, moulds and endotoxins were measured during the summer months. Sixty bacterial and 20 fungal species have been identified in these bioaerosols by molecular or cultivation techniques. *Salmonella* species and *Escherichia coli* have been cultured from biomass.

Several cross-sectional studies reported increased ocular, nasal, respiratory, skin and gastro-intestinal symptoms in these workers (Table 1). A few authors suggested a dose–response effect for health effects; however, on the basis of a systematic review, a bioaerosols expert network concluded that there was insufficient evidence to derive health-based exposure limits [35]. There were also reports of adaptation by some workers to the acute effects of exposure or a healthy worker effect. Although reviews referred to organic dust toxic syndrome as a consequence of exposure to bioaerosol, there was no case report of this in compost workers, although there are reports in pig and poultry farmers, mulch spreaders, wood chip and mushroom workers.

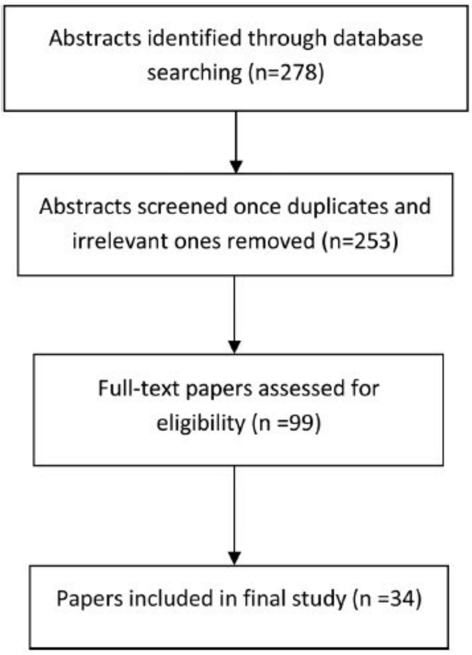

Figure 1. PRISMA flow chart for compost, municipal and hazardous waste papers.

Increased inflammatory or immunological markers such as neutrophils, interleukin-6 or -8 and immunoglobulins were found in the nasal fluid, sputum, breath condensate or the serum of waste and recycling workers with correlation to symptoms and exposure to endotoxins and beta-glucans [23,24,36].

Sensitization to components of the bioaerosols such as *Thermophilic actinomycetes* and *Aspergillus fumigatus* was found in serum. There were a few case reports of allergic disease such as extrinsic allergic alveolitis (hypersensitivity pneumonitis), allergic bronchopulmonary aspergillosis and occupational asthma (Table 1). There was one longitudinal German study that showed declining forced vital capacity % (FVC%) greater than controls over a 5-year period [20]. Others have found a significant decline in forced expiratory volume in 1 s (FEV_1) and FEV_1/FVC% and an increase in methacholine responsiveness during the working week. Although raised levels of serum IgG to fungi have been reported, the largest study to date found no difference in total IgE or rates of sensitization to fungi between compost workers and controls [17].

Although *Legionella pneumophilia* and *Legionella longbeachae* may be found in compost [37], there were no reports of Legionnaire's disease in these workers. An outbreak of Q fever due to *Coxiella burnetii* in at least 50 workers was reported from a site that was probably contaminated with animal carcasses [30].

Asphyxiation of two workers by hydrogen sulphide from rotting animal waste was also reported [33]. The importance of personal protective equipment has been stressed, but cabs have to be well maintained and windows kept closed. Components of the bioaerosols have been found on the inside of respiratory protective equipment.

Municipal waste incinerator emissions to air and fly ash waste containing heavy metals, polychlorinated dioxins, dibenzofurans, polycyclic aromatic hydrocarbons and particulate matter were reported, but there were no reported illnesses from these exposures. Three cross-sectional studies of hazardous waste incinerator workers showed mean concentrations of heavy metals, polychlorinated dioxins and biphenyls in blood or urine to be no different from controls in newer incinerators [38–40]. Exposure to solvents in paint is another potential hazard, but no cases of occupational illness from this were found.

In the metal, batteries, cables and wires recycling sub-sector, 74 papers were identified, including 12 observational health studies and four case reports of health outcomes. The remainder were non-clinical reports, studies without controls, studies of local populations or environmental contamination, irrelevant or duplicate papers. The selected papers included several studies showing significant exposure to heavy metal particulates, particularly lead when torch cutting metal

Table 1. Conclusions and quality ratings for composting, municipal solid and toxic waste health studies

Systematic and narrative reviews	Topic	Main conclusions	Quality rating
			SIGN
Pearson *et al.* (2015) [5]	Exposures and health outcomes in workers and residents in relation to emissions from composting facilities	66 studies, mainly cross-sectional. Bioaerosol concentrations highest on-site during agitation activities (turning, shredding and screening). Sampling generally short-term and number of workers generally small. Only one longitudinal study. Occupational studies suggest a higher risk of respiratory illnesses with higher bioaerosol exposures. Need for more objective measures of health effects	2++
Searl and Crawford (2012) [6]	Health risks in waste and recycling	Increased risk of ill-health related to specific activities and exposure to bioaerosols. Use of agency workers, poor personal hygiene and failure to follow safe working procedures are relevant to causation	2++
Binion and Gutberlet (2012) [7]	Review of the well-being of recyclers	Poor working conditions, poor health, the need for worker co-operatives and the enforcement of health protection policies are discussed	4
Porta *et al.* (2009) [8]	Health effects associated with the management of solid waste	The evidence suggests an association but is not sufficient to establish a causal relationship between exposure and health effects	2++
Giusti (2009) [9]	The impact of waste management practices on health	High fatal and non-fatal accident rates. Review included exposure to bioaerosols from sewage treatment plants and the effects on health of residents living near recycling plants. A request for better quality cohort studies with exposure measurements was made	4
Domingo and Nadal (2009) [10]	Health risks from domestic composting facilities	Control of biological hazards, workplace measurements of microorganisms and VOCs, PPE, analysis of compost for biological and chemical agents before agricultural application and the importance of health surveillance	4
Fleming *et al.* (2002) [11]	Occupational exposures and health risks in solid waste workers	Solid waste workers experience acute and chronic musculoskeletal, dermal and respiratory health effects	2++
Poulsen *et al.* (1995) [12]	Occupational health problems in domestic waste collection and their causes	Increased risk of accidents, musculoskeletal, gastrointestinal, eye and skin problems; chronic bronchitis and organic dust toxic syndrome. There is a need to link exposures to occupational health problems	4

Cross-sectional and longitudinal studies	Topic	Sample	Main findings	Quality rating
				Newcastle-Ottawa (0–10)
Heldal *et al.* (2015) [13]	Work-related cough and lung function	47 compost workers, 37 controls in Norway	Actinomycetes spore count was associated with work-related cough and cross-shift decrease in FEV_1/FVC%	9
Schantora *et al.* (2015) [14]	Upper and lower airway symptoms, lung function tests	69 waste collectors in Germany	Rhinitis and cough positively associated. Prevalence of cough and chronic bronchitis not associated with duration of employment	6
Garrido *et al.* (2015) [15]	Health status and HRQoL	63 municipal waste collectors in Germany	67% of collectors reported back pain which was associated with impairments in HRQoL scores	3
Hoffmeyer *et al.* (2014) [16]	Rhinoconjunctivitis and lower airway disease	190 current and 59 former compost workers in Germany	Eye and nose irritation not due to atopy. Chronic bronchitis in former workers probably due to chronic irritation from bioaerosol	9
Van Kampen *et al.* (2012) [17]	Respiratory symptoms, spirometry, specific IgE/G to fungi and actinomycetes	190 current, 59 former compost workers, 38 controls in Germany	Increased rates of conjunctivitis in current workers compared to controls; 75% of symptoms improved or disappeared after leaving composting. Cough and dyspnoea persisted in 39 and 20%, respectively, of former workers. %FVC reduced in compost workers. No difference in IgG or IgE antibody levels	8
Hambach *et al.* (2012) [18]	Work-related health symptoms	31 compost workers, 31 controls in Belgium	Higher prevalence of respiratory, gastrointestinal and skin complaints in compost workers	8

Table 1. Continued

Cross-sectional and longitudinal studies	Topic	Sample	Main findings	Quality rating Newcastle-Ottawa (0–10)
Athanasiou *et al.* (2010) [19]	Respiratory symptoms and lung function	104 domestic waste workers, 80 controls in Greece	Increased cough and sore throats and reduced FVC in waste workers	6
Bunger *et al.* (2007) [20]	Respiratory disorders and lung function in compost workers with 5 years of follow-up	123 compost workers, 48 controls in Germany	Higher prevalence of conjunctivitis and chronic bronchitis in compost workers. Significant FVC% decline in non-smoking compost workers compared to controls	9
De Meer *et al.* (2007) [21]	Methacholine responsiveness over the working week	6 cases with and 10 controls without respiratory symptoms who loaded domestic waste in The Netherlands	Methacholine responsiveness increased over the working week in subjects but not controls. There was no change in other lung function tests	5
Heldal and Eduard (2004) [22]	Symptoms and exposure to bioaerosols	22 domestic waste workers in Norway	Increased nasal irritation with exposure to bacteria; increased cough with exposure to fungi	5
Heldal *et al.* (2003) [23]	Lung function and inflammatory markers in food and garden waste collectors	22 domestic waste collectors in Norway	Increased neutrophils and IL-8 in sputum and reduced lung function cross-shift. Inflammatory response correlated with endotoxin levels ($r = 0.55$)	5
Wouters *et al.* (2002) [24]	Respiratory symptoms, upper airway inflammation	47 waste collectors, 15 controls in The Netherlands	Prevalence of respiratory symptoms higher in collectors and associated with increased concentrations of neutrophils and IL-8 in nasal fluid	9
Bunger *et al.* (2000) [25]	Health complaints and immunological markers	58 compost workers, 53 collectors, 40 controls in Germany	Compost workers had higher prevalence of respiratory and skin complaints than other groups, as well as higher IgG concentrations against fungi and actinomycetes	9
Ivens *et al.* (1999) [26]	Gastro-intestinal symptoms and relationship with bioaerosols exposures	1747 domestic waste collectors, 1111 controls in Denmark	Increased self-reported nausea and diarrhoea with increasing exposures to endotoxins and fungi	9
Ivens *et al.* (1997) [27]	Occupational injuries	667 domestic waste collectors in Denmark	17% of employees experienced injury. Number of injuries decreased with experience	8
Hansen *et al.* (1997) [28]	Respiratory symptoms and relationship to exposure to bioaerosols	1515 waste collectors, 423 controls in Denmark	Waste collectors had significantly higher prevalence of cough, nasal irritation, wheeze and chronic bronchitis. Prevalence of chronic bronchitis was associated with high exposure to total microorganisms and fungi	6
Coenen *et al.* (1997) [29]	Respiratory symptoms, lung function and sensitization to moulds	63 domestic waste collectors in Denmark	Increased MMI symptoms in collectors of garden waste; increased variability of peak flow in those with high exposure to *Aspergillus fumigatus*; increased IgG levels in those with high exposure to endotoxins	3

Case reports	Main findings	Quality rating SIGN
Alonso *et al.* (2015) [30]	Outbreak of Q fever affecting 62 employees at a waste sorting plant in Bilbao, Spain	3
Poole and Wong (2014) [31]	2 cases of ABPA in municipal garden waste collectors in UK	3
Bunger *et al.* (2007) [20]	3 cases of EAA in compost workers in Germany	3
Allmers *et al.* (2000) [32]	1 case of OA and ABPA in a municipal waste collector in Germany	3
Anon (2009) [33]	Asphyxiation of 2 workers by hydrogen sulphide gas from rotting animal waste in Scotland	3

ABPA, allergic bronchopulmonary aspergillosis; EAA, extrinsic allergic alveolitis; HRQoL, health-related quality of life; IgE, immunoglobulin E; IgG, immunoglobulin G; IL-8, interleukin-8; MMI, mucosal membrane irritation; OA, occupational asthma; VOCs, volatile organic compounds.

plate and from lead-acid battery recycling. Three papers reported raised ambient levels of dioxins and dibenzofurans [41] and one of raised serum markers of oxidative stress in workers engaged in the melting of scrap metal.

There were reports of raised blood lead in children living near or working in lead-acid battery recycling factories in various parts of the world and being fatally or sub-clinically poisoned with lead [42]. Children of metal or battery recycling workers were found to have raised blood lead from dust carried home on their parents' clothing [43].

There was one case report from Italy of a worker recycling lead-acid batteries developing anaemia and polyneuropathy due to lead poisoning [44]. Urinary mercury in excess of the biological exposure index was reported in alkaline battery recycling workers [45]. There is also the potential to be exposed to toxic levels of other heavy metals, such as cobalt, lead and copper from the recycling of lithium-ion batteries. Four factories in the USA that recycled lead-sheathed copper telephone cables were closed after workers were found to have high concentrations of blood lead [46].

There were several reports of radioactive material being found among scrap metal and a few of radioactive material getting into the finished product [47]. Particulates in air containing hexavalent chromium or lead may also be relevant because of their carcinogenic risk. Exposure to dioxins from the thermal degradation of printed circuit boards was reported, but no health effects [48].

In the glass and fluorescent lights recycling sub-sector, 16 papers were identified, to include one observational health study and two case reports. The others were mainly non-medical reports about ambient levels of mercury, lead, dust, bioaerosols and noise. Although the main hazards are probably noise from the tipping of glass [49] and ergonomic problems when boxes of glass are manually handled, very little about this has reached the published literature.

A cross-sectional study reported increased nasal and chest symptoms from presumed fungal and particulate exposure in glass recyclers [50]. There was one case report of raised blood lead in a worker and his two children from the recycling of cathode ray tubes that were made from a leaded glass [51].

In the recycling of fluorescent lights, there is potential for exposure to mercury vapour and to dust containing lead and yttrium. There was a case report of two workers from a fluorescent tube recycling factory in Germany, one with membranous glomerulonephritis and the other with nephrotic syndrome due to mercury poisoning [52]. There was also reference to a case of chronic mercury poisoning in a glassblower in a fluorescent lamp manufacturer in the UK [53]. The disposal of solar photovoltaic panels containing heavy metals such as cadmium has not been reported to be associated with any health effects.

In the landfill, textile and wood recycling sub-sector, 44 papers were identified to include six observational health studies and one case report. The rest were mainly hygiene studies of emissions to air or of ground eluates. The main hazards from landfill were identified to be exposure to dust, metal particulates, bioaerosols to include endotoxins, asbestos fibres and truck exhaust emissions. There were two cross-sectional studies from the USA reporting increased dermatological, respiratory, throat and gastro-intestinal symptoms in landfill workers [54,55]. Raised total serum IgE levels were found in landfill workers, but these levels did not correlate with symptoms.

The sorting and shredding of fabric for recycling may be associated with high exposures to cotton dust and endotoxin [56]. Textile workers may experience rhino-conjunctivitis and respiratory symptoms on the first day back at work, which improves with persistent exposure throughout the working week (byssinosis). Symptoms may persist throughout the week and lead to chronic lung disease. Cross-shift falls in FEV_1, non-specific bronchial hyper-reactivity and an accelerated longitudinal decline in FEV_1 have been reported [45,57,58], but there were no case reports of byssinosis.

High concentrations of dust in excess of the Workplace Exposure Limit of 5 mg/m^3 and of airborne micro-organisms, particularly fungi, and bacterial endotoxins were measured in wood (to include fibreboard and chipboard) recycling factories, particularly during shredding and cleaning processes and when storing wood chips, but no reports of occupational illness were found. Irritant-induced asthma was reported in three workers in a wood burning waste facility in Germany [59] and two cases of acute pulmonary aspergillosis on exposure to bark chippings [60].

In the medical waste, paper and nappy recycling sub-sector, 45 papers were identified to include six observational health studies and one case report. The majority of the other papers were commentaries about the toxicity of medical waste; studies to measure the pharmacological, steroid hormone or radioactive contamination of waste; or studies of the dust and bioaerosol levels generated from paper recycling. The main hazards for medical waste handlers are sharp injuries and exposure to blood or blood stained materials. Pathogenic infections, toxic chemicals and radioactive materials are other potential hazards. Blood splashes to the face were reported in workers handling medical waste. There were no reports of occupational infections caught from medical waste; however, increased seropositivity to HBV and HCV in these workers has been reported from Greece and Libya.

For paper recycling, other than the potential consequences of manual handling, the recycling of clean, dry paper does not appear to be hazardous. Paper or cardboard stored damp or if contaminated with organic material such as faeces may be associated with concentrations of bacteria up to 10^6 cells/m^3 or fungi up to 10^6 cfu/m^3. There was one cross-sectional study of increased respiratory symptoms, increased inflammatory markers in serum and increased methacholine bronchial reactivity in paper workers [61]; one case report of occupational asthma due to hydroxylamine used for 'de-inking' in a paper recycling factory in the UK [62] and an abstract reporting increased sensitization to storage mites in recycling paper-mill workers.

There was one report of concentrations of enteric pathogens in a municipal domestic solid waste site to which nappies were added, but levels were found to be below the detection limit suggesting that they were destroyed in the composting process.

The WEEE sector includes white goods, telephones, televisions, printed circuit boards and printers, much of which is transported to low labour cost countries for the recovery of precious metals. Sixty-five papers were identified to include 12 cross-sectional studies and three case reports of health outcomes. Most of the research came from China.

Apart from heavy manual handling, the main hazards in this sector are exposure to heavy metals such as copper, silver and gold, as well as dioxins, furans and polycyclic aromatic hydrocarbons. Cross-sectional studies using biological monitoring showed raised serum levels in workers of copper, cadmium, lead, cobalt, mercury, polycyclic aromatic hydrocarbons and platinum from catalytic converters. Exposure to polybrominated diphenyl ethers (a flame retardant) and raised levels in the blood of workers were found in WEEE recyclers [63]. Abnormal thyroid function, adverse neonatal outcomes, chromosomal aberrations and DNA damage were also reported [64]. Exposure to heavy metals has been associated with abnormal lung function in children and neonatal defects including stillbirths, premature births and low birth weights in China [65]. There was one case report from the USA of argyria in an X-ray and photographic recycler [66].

HSE's Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR) identified four cases of occupational asthma, two of Q fever, two of leptospirosis, one of extrinsic allergic alveolitis, one of contact dermatitis and a cluster of lead poisoning in the waste and recycling sector from 2005 to 2015. Some of these cases led to enforcement action against the employer. There was no information about the evidence for diagnosis or attribution.

The THOR network, University of Manchester identified 371 cases of work-related illness diagnosed by a doctor in the waste and recycling sector between 1989 and 2015. Because some reporters collect work-related illness for only 1 month of the year, this corresponds with an estimated incidence of 1504 cases (M. Carder, personal communication). As the schemes have not been running concurrently, no attempt was made to calculate the rate per year.

For OPRA, most cases in this sector were musculoskeletal involving the back and upper limbs to include injuries, fractures, epicondylitis and tenosynovitis, but there were also cases of contact dermatitis, asbestos-related lung disease, Q fever, leptospirosis and three fatalities from toxic gas.

For SWORD, most cases were of asbestos-related lung disease and asthma due to exposure to dust, bioaerosols and chemicals such as isocyanates, solvents and methane.

For EPIDERM, most cases were of contact dermatitis due to irritants to include oils and solvents, or sensitizers in gloves such as thiurams, mercapto mix and chromates, as well as neoplastic disease from sunlight.

For THOR-GP and MOSS, most cases were musculoskeletal from heavy manual handling, but included one case of lead poisoning. For SOSMI, there were cases of anxiety, depression and post-traumatic stress disorder; SIDAW diarrhoeal disease and leptospirosis and OSSA noise-induced hearing loss. The hazards and health effects for the waste and recycling industries are summarized in Table 2.

Discussion

This review found that the main occupational hazards in the waste and recycling sector are heavy manual handling and exposure to bioaerosols, heavy metals and organic pollutants. The majority of research has examined bioaerosol emissions and the health complaints of workers in the green waste sector, with most studies of a cross-sectional design and of variable quality. Bioaerosol exposures were associated with eye, nose, throat and respiratory symptoms of a toxic, irritant or allergic origin. Abnormal lung function, bronchial hyper-reactivity and increased inflammatory markers in nasal fluid, sputum or serum were also identified in compost workers as well as sensitization to *A. fumigatus* and *T. actinomycetes*, but whether they are more likely to develop allergic disease due to their workplace exposures is unknown. There were six cases of extrinsic allergic alveolitis, allergic bronchopulmonary aspergillosis and occupational asthma in compost workers identified by this search strategy. Five other /cases were reported under RIDDOR, but it was not possible to attribute them to a specific exposure or sector of the waste and recycling sector.

Fewer studies were found in the metal, battery, cable and wire recycling sector with most reporting exposure to heavy metal particulates, particularly lead. There was limited research examining occupational hazards in other sectors. There were three case reports of mercury poisoning from fluorescent light recycling. Wood recycling was associated with

Table 2. Hazards and health effects by activity

Recycling activity	Hazards to health	Reported clinical and biological effects
Composting, municipal solid and toxic waste	Heavy manual handling, inorganic dust, bioaerosols, VOCs, PAHs, heavy metals, dioxins, furans	Fatal and non-fatal injuries, MMI, OA, EAA, ABPA, asbestos-related lung disease, abnormal lung function, gastro-intestinal disease, contact dermatitis, Q fever, leptospirosis
Metals, batteries, cables, wires and catalytic converters	Inorganic dust, lead, other heavy metals to include Hg and Pt, noise, radioactive materials, dioxins, furans	Pb poisoning in lead-acid battery; raised urinary Hg in alkaline battery workers
Glass to include cathode ray tubes	Noise, bioaerosols	MMI, raised blood Pb
Fluorescent lights	Inorganic dust, metal fume, mercury, lead, yttrium	Hg and Pb poisoning, MGN and nephrotic syndrome
Landfill	Inorganic dust, bioaerosols, asbestos, gases	MMI, respiratory, dermatological and gastro-intestinal symptoms
Textiles	Organic dust, bioaerosols	MMI, respiratory symptoms, abnormal lung function tests, byssinosis, COPD, OA
Wood, chipboard and bark chippings	Dust, bioaerosols	Acute pulmonary aspergillosis from bark chippings; OA from burning wood; MMI, OA, EAA, COPD from manufacturing with wood
Medical waste	Sharps, blood-borne viruses, radioactive materials, heavy metals in incinerator ash	Seroconversion from sharps injury
Paper	Organic contamination, bioaerosols	MMI, OA, sensitization to storage mites
WEEE	Heavy manual handling, inorganic dust, PAHs, heavy metals, dioxins, furans, brominated diphenyl ethers (flame retardants)	Respiratory symptoms, abnormal lung function, adverse neonatal outcomes, chromosomal aberrations, argyria

ABPA, allergic bronchopulmonary aspergillosis; COPD, chronic obstructive pulmonary disease; EAA, extrinsic allergic alveolitis (hypersensitivity pneumonitis); Hg, mercury; MGN, membranous glomerulonephritis; MMI, mucosal membrane irritation; OA, occupational asthma; PAH, polycyclic aromatic hydrocarbons; Pb, lead; Pt, platinum; VOCs, volatile organic compounds.

exposure to bioaerosols with case reports of asthma and pulmonary aspergillosis. There were no reports of occupational illness from the recycling of medical or paper waste.

A strength of this review is the inclusion of a wide range of waste and recycling activities and the professionally guided scrutiny of a number of different databases. We can be confident therefore that we have collated all the reported evidence for health effects associated with working in the waste and recycling sector. The use of grading systems adds further value, so that those wishing to examine the literature in this field may direct their attention to particular studies. In the absence of an established grading system for cross-sectional studies, we used a modified version of the Newcastle-Ottawa Scale (NOS) to score them in a systematic way. Although the NOS has been criticized for lacking an evidence base for case–control and cohort studies [67], it has been used for several other systematic reviews of cross-sectional studies. Assessing the quality of the papers in the non-composting industries in a systematic way was not undertaken, as they were relatively few in number. We do not believe that this detracts from the quality or usefulness of this review.

Limitations of this review include the small number of cases of illness retrieved from the world's scientific literature and the inability to link cases to specific parts of the waste and recycling sector identified by the UK's regulatory (RIDDOR) and national surveillance (THOR) schemes. Very few, if any, of these cases appear to have been reported in the literature. Minor illnesses such as rhinoconjunctivitis and gastric upsets will probably have gone unreported by these schemes. Furthermore, the rigour by which diagnoses and attribution of the cases that were reported was established is unknown. It is likely therefore that much work-related illness went uncaptured by the surveillance schemes and the scientifically reviewed literature. It is important therefore that doctors investigate and report cases of work-related illness.

Some studies suggested a dose–response relationship for the health effects seen in compost workers, but a recent review of the evidence concluded that there was not strong enough evidence to set exposure limits [35]. Controls to contain the bioaerosols or limit the exposure of workers to them by the use of air-conditioned vehicles or personal protective equipment may not be effective due to problems with maintenance and compliance. More research is required to link exposure to the components of bioaerosols to symptoms and ill-health in workers. The evidence indicated that workers exposed to compost were at an increased risk of occupational illness for which regular health surveillance may assist in identifying early cases of disease and the medically vulnerable. The recycling of food waste will expose workers to similar bioaerosols. Although municipal waste workers not exposed to garden waste may be exposed to other hazards from incinerator fly ash such as heavy metals, dioxins, furans and polycyclic hydrocarbons, there was no evidence from the literature that these exposures had caused significant biological effects or illness.

Workers in the metal, battery (lead acid, alkaline, lithium ion) and cable recycling sector may be exposed to heavy metals including lead, mercury, copper and cobalt. Raised blood lead in workers and in their families has been reported reinforcing the importance of workplace controls and personal hygiene. For UK workers, the Control of Lead at Work Regulations 2002 will apply to many of these workplaces for which biological monitoring will be required. Whether this should be undertaken for other heavy metals will be determined by health surveillance where cases of ill-health have been detected or where there is a need to know if workers are being exposed to significant concentrations of these metals from their exposure to dust or fume.

Some health effects identified might be regarded as 'unexpected' such as mucosal membrane irritation from microbiologically contaminated glass, raised blood lead from recycling of cathode ray tubes, adverse neonatal outcomes from recycling of e-waste or acute pulmonary aspergillosis from exposure to tree bark, which illustrates the importance of a good understanding of the constituents of the materials being recycled and their potential breakdown products.

The geographical variations in the way that these industries operate and the adequacy of controls will in part determine what health effects occur. A site-specific risk assessment with occupational health input, in conjunction with this review, should help with decision-making about the need for health surveillance. Such surveillance might include a health questionnaire tailored to the relevant hazards, exposures and likely health effects, testing for sensitization, lung function tests and biological monitoring.

Key points

- Waste and recycling workers are at increased risk of ill-health, the nature of which is specific to the sector and geographical location in which they work.
- This review found that exposure to bioaerosols, heavy metals and organic pollutants were the main occupational hazards.
- This review should help to inform risk assessment across the sector.

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Conflicts of interest

None declared.

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Developing a questionnaire to assess the health effects of bioaerosols

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Background Bioaerosol exposure occurs in several industries including green waste recycling, poultry farming, grain, animal feed and cotton production. Whilst several studies have investigated exposure and health effects in compost workers, the best questions to ask about health are uncertain.

Aims This study aimed to develop a questionnaire to assess health symptoms in compost workers.

Methods A 46-item questionnaire to ascertain possible symptoms of occupational illness related to bioaerosol exposure in a cohort of UK industrial compost workers and delivery in an interviewer-led format. The reliability of the questionnaire was assessed using Cronbach's α. A principal component analysis (PCA) was conducted to condense the questionnaire for practical purposes.

Results One hundred and eleven (89%) workers completed the questionnaire. All items showed very good reliability (Cronbach's $\alpha = 0.83$). After removing perfectly correlated questions from the data set, the PCA was conducted on a reduced data set of 28 items to explore underlying themes. Nine components were identified that explained 77% of the total variation. Nine of the questions removed prior to PCA due to perfect correlation were reintroduced because they added clinical value. The final questionnaire therefore consisted of 37 items and retained very adequate reliability (Cronbach's $\alpha = 0.76$).

Conclusions Our health questionnaire has demonstrated adequate reliability when used within this industrial composting workforce. Further applications may include health surveillance, investigating outbreaks of occupational disease or research. Future work should examine the predictive validity of the questionnaire in these settings.

Key words Occupational lung diseases; questionnaire; respiratory; surveillance; workplace hazards.

Introduction

Bioaerosols are naturally occurring aerosolized particles of microbial, plant or animal origin [1]. They are found extensively on the surfaces of organic material such as animals, plants and soil, as well as in human and animal nasal cavities. Such particulates include living or dead fungi and bacteria, structures produced by the organism such as fungal spores, or secreted by them such as endotoxins from bacteria and mycotoxins from fungi. They are thought to induce disease through toxic, irritant and allergic mechanisms [2].

Bioaerosol exposure is linked to numerous health conditions including rhino-conjunctivitis, chronic bronchitis, occupational asthma, dermatitis and gastrointestinal upset [3]. The fungus *Aspergillus fumigatus* has the potential to cause a broad spectrum of respiratory illness including allergic bronchopulmonary aspergillosis (ABPA) and allergic aspergillus sinusitis, aspergilloma and invasive disease such as invasive aspergillosis, airway invasive aspergillosis and chronic necrotizing pulmonary aspergillosis [4]. Pulmonary conditions such as extrinsic allergic alveolitis (EAA), which involves a type III and type IV immune hypersensitivity reaction to fungi or bacteria, have been reported [5]. EAA is often associated to working with contaminated mouldy hay, but similar illnesses are linked to the microbial contamination of sugar cane, mushrooms, air conditions, hot tubs and musical instruments. There are also reports of a similar flu-like illness characterized by myalgia, fevers, chills and cough in response to organic dust exposure called organic dust toxic syndrome (ODTS) [6].

Bioaerosol exposure occurs in several industries including domestic and green waste (compost) recycling, poultry farming, grain and animal feed production, through flour and bacterial enzymes in the baking industry, cotton and textile industries, as well as the wood and paper industries. Despite the potential health risks associated with exposure, there are currently no legal occupational exposure limits in the UK [7]. Although the Dutch Expert Committee on Occupational Safety has recommended an occupational exposure limit of 90 EU/m^3 or 5 ng/m^3 over an 8-h period for endotoxin, such proposals have not been adopted widely elsewhere [8]. Health surveillance may be indicated in instances where bioaerosol exposure cannot be sufficiently controlled or where a risk assessment indicates a need. The primary goal of health surveillance is to detect early signs of occupational illness, so that appropriate medical treatment can be initiated, and risk assessments reviewed.

Questionnaires are commonly used in health surveillance programmes to identify symptoms of possible work-related illness. Several standardized health questionnaires exist to assess symptoms suggestive of obstructive or respiratory lung disease [9,10]. However, it is not certain whether these are appropriate for industries in which bioaerosol exposure occurs, and if they are sensitive or specific enough to detect rarer conditions such as EAA, ODTS and ABPA which have their own symptoms. For example, the Health and Safety Executive (HSE) in Great Britain recommends the administration of an annual health questionnaire for workers in the grain industry but not what questions should be asked. Previous studies examining health symptoms in compost workers refer to using health questionnaires for this purpose, but none have reported the specific questions that were asked, and few have commented on how they were administered. Accordingly, the aim of this study was to devise, implement and evaluate a health questionnaire to detect possible symptoms of occupational illness related to bioaerosol exposure.

Methods

Two occupational physicians (S.B. and J.P.) based at the HSE developed a questionnaire to identify early signs of occupational illness related to bioaerosol exposure. Initially, the occupational physicians reviewed a standardized questionnaire, which had been used by the HSE previously to assess symptoms of occupational respiratory illness in workplaces such as grain, baking and foundry industries. S.B. and J.P. made some amendments to the wording of existing questions and added a few additional items to cover symptoms of other illness that may be associated with bioaerosol exposure including EAA, ODTS, ABPA and dermatitis. Questions relating to gastrointestinal upset were excluded because of lack of specificity.

The final questionnaire consisted of four sections and was designed to identify work-related illness. Section A captured demographic data and Section B enquired about occupational history such as length of time in the role and current work tasks performed, with a focus on high-exposure tasks such as compost turning, shredding and screening. Section C collected data about the type of respiratory protective equipment (RPE) used by the workers, the length of time it was used and tasks for which it was worn. Section D assessed workers' health complaints. A final free-text comment box was included if the worker wished to highlight any further issues regarding their job or their health which they felt might be of relevance to the study. Four HSE academic experts (one occupational physician, one immunologist, one microbiologist and one scientist) provided verbal and written feedback about the scientific content of the questionnaire prior to administration. Two industry safety managers also reviewed the questionnaire's appropriateness and understanding for their workforces.

The questionnaire was delivered across six medium- to large-sized composting companies in the UK between July 2015 and July 2016. All workers at each company were invited to complete the questionnaire. We used an interviewer-administered format, with responses recorded by S.B. We assessed the reliability of the questionnaire using the internal consistency approach denoted by Cronbach's alpha (α). Using a scale from 0 to 1; a value of 0.90 or above is considered as 'excellent reliability', 0.80–0.89 as 'very good' and 0.70–0.79 as 'adequate' [11].

As we wished to create a more concise questionnaire but one which retained the variety of the original, we conducted a principal component analysis (PCA) to determine which items could be reasonably omitted from the questionnaire whilst retaining its qualities in detecting important symptoms of occupational respiratory illness related to bioaerosol exposure. PCA is a data reduction technique that partitions the data into a set of components signifying uncorrelated variables, with each component a linear combination of the original variables [12]. Its purpose is to minimize repetition whilst maximizing the variety of information covered by the original questionnaire. Eigenvalues, a measure of the variance of each component, were calculated to determine which components should be retained and which should be rejected. Traditionally, it has been recommended that components with eigenvalues below 1 should be rejected since each component should not account for less of the variance in the data set than the individual question itself [13].

We analysed the data using Stata/MP 15.0 for Windows [14]. The National Research Ethics Service Committee Northwest provided ethical approval for the study (reference number 14/NW/0188). We stored all data in a secure location at the HSE Laboratories in Buxton, England and treated it with the strictest confidence.

Results

One hundred and eleven of 125 (89%) workers completed the questionnaire. Most participants were male (n = 103;

93%), with the eight female participants all working in office environments. The health questions asked in the study are shown in Table 1. Cronbach's α for the complete 46-item questionnaire was 0.83. The results show that the questionnaire retained very good internal consistency when any individual item was removed (Cronbach's α remained > 0.8). Those questions amended or added by the occupational physicians are shown in italics. We omitted Questions 3, 16 and 19 from the reliability analysis as all participants answered them identically.

Producing a matrix of Spearman's correlation coefficients identified several questions that were perfectly

Table 1. Health questionnaire items and corresponding reliability values (Cronbach's α)

Question	Cronbach's α if item removed
1. Have you ever been diagnosed by a doctor with asthma?	0.833
2. Have you ever been diagnosed by a doctor with chronic obstructive pulmonary disease?	0.833
3. Have you ever been diagnosed by a doctor with another chest problem?	N/A
4. Have you ever been diagnosed by a doctor with eczema?	0.831
5. Have you ever been diagnosed by a doctor with hay fever?	0.828
6. Have you ever been diagnosed by a doctor any form of allergy?	0.833
7. Do you take medicines for asthma such as inhalers or tablets?	0.834
8. Do you smoke *outside of work?*	0.839
9. In the last 12 months has your chest become tight?	0.830
10. In the last 12 months have you been woken up because of chest tightness?	0.833
11. Do you only get chest tightness with colds?	0.844
12. Is your chest tightness better, the same or worse away from work?	0.827
13. Is your chest tightness better, the same or worse on holiday?	0.827
14. In the last 12 months have you had shortness of breath when walking or at rest?	0.826
15. In the last 12 months have you been woken up because of shortness of breath?	0.834
16. Do you only get shortness of breath with colds?	N/A
17. Is your shortness of breath better, the same or worse away from work?	0.827
18. Is your shortness of breath better, the same or worse on holiday?	0.827
19. In the last 12 months have you experienced wheezing or whistling in your chest?	N/A
20. In the last 12 months have you been woken up with wheezing/whistling in your chest?	0.833
21. Do you only get chest wheezing or whistling with colds?	0.844
22. Is your wheezing or whistling better, the same or worse away from work?	0.834
23. Is your wheezing or whistling better, the same or worse on holiday?	0.834
24. In the last 12 months have you had a cough that has kept you awake at night?	0.829
25. Do you usually cough first thing in the morning in winter?	0.828
26. Do you usually cough at other times of the day or night in winter?	0.824
27. Do you usually bring up any phlegm from your chest when you cough?	0.828
28. Do you cough like this on most days for as much as 3 months of the year?	0.830
29. Have you ever coughed up any green plugs or brown strings?	0.836
30. Is your cough better, the same or worse away from work?	0.828
31. Is your cough better, the same or worse on holiday?	0.828
32. In the last 12 months have you had unexplained weight loss?	0.834
33. In the last 12 months have you had unexplained flu-like symptoms?	0.828
34. In the last 12 months have you had unexplained fevers?	0.828
35. In the last 12 months have you had unexplained shivering?	0.838
36. In the last 12 months have you had unexplained joint or muscle aches?	0.828
37. In the last 12 months have you had unexplained general feelings of being unwell?	0.828
38. Do you ever suffer from irritation of your eyes such as pricking, itching, burning, dryness, watering, soreness or stinging of the eyes?	0.825
39. Is/was your eye irritation better, the same or worse away from work?	0.823
40. Is/was your eye irritation better, the same or worse on holiday?	0.823
41. Apart from when you have a cold, do you ever suffer from irritation of your nose such as pricking, itching, burning or a runny, dry or blocked nose?	0.820
42. Is/was your nose irritation better, the same or worse away from work?	0.819
43. Is/was your nose irritation better, the same or worse on holiday?	0.819
44. Do you have, or have you ever had a rash that you attribute to work?	0.833
45. Does your rash get better, stay the same or get worse away from work?	0.833
46. Does your rash get better, stay the same or get worse on holiday?	0.833

N/A, not applicable.

correlated, which were dropped from the PCA. To address this before analysis, the '_rmcoll' command in Stata was used to identify and drop collinear variables from the PCA. These were Questions 3, 10, 13, 16, 17, 18, 19, 23, 31, 32, 35, 36, 37, 39, 40, 43, 45 and 46.

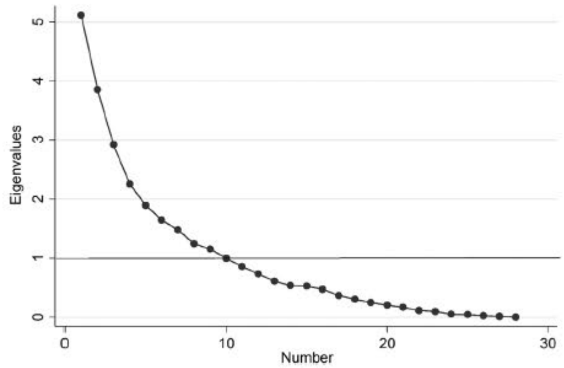

Figure 1. Scree plot of eigenvalues after PCA.

A PCA was performed on the 28 remaining items and the eigenvalues for the resulting components are shown in the scree plot (Figure 1). Using the Kaiser–Guttman criterion of retaining components with eigenvalues greater than 1, the plot suggested that nine components should be retained, which cumulatively explained 77% of the variance in the data.

The PCA was then rerun retaining a nine-component solution and the solution rotated using the oblique oblimin rotation, which allows for correlations between components as opposed to alternative techniques. To promote clarity around component identification, a component loading cut-off criterion of >0.4 was set. The component loading patterns based on this criterion are summarized in Table 2 with loadings >0.4 shown in bold font.

Finally, the occupational physicians examined the items excluded from the PCA due to perfect correlation to determine whether any added clinical value to the 28 retained questions. Q10 and Q20 were both reinstated as each added descriptive value to help characterize symptoms of possible asthma and chronic obstructive pulmonary disease. Similarly, Q29 and Q32 were reintroduced

Table 2. Rotated factor loadings

Question	Comp 1	Comp 2	Comp 3	Comp 4	Comp 5	Comp 6	Comp 7	Comp 8	Comp 9
Q1	−0.05	0.25	−0.06	0.11	0.01	0.02	0.39	0.13	−0.28
Q2	−0.06	−0.06	−0.01	−0.01	0.01	−0.04	0.03	**−0.66**	−0.02
Q4	−0.01	0.04	0.10	−0.03	0.16	0.03	0.19	0.05	**0.61**
Q5	−0.06	−0.05	0.10	−0.03	0.16	0.04	0.19	0.21	0.03
Q6	0.05	0.02	−0.01	−0.10	−0.03	−0.07	**0.64**	−0.04	0.10
Q7	−0.05	0.39	−0.01	0.08	0.00	0.04	0.12	0.17	−0.20
Q8	0.32	0.00	0.09	−0.15	0.02	−0.23	0.07	−0.05	0.00
Q9	−0.04	0.26	**0.45**	0.06	−0.02	−0.04	−0.07	0.07	−0.03
Q11	0.04	−0.30	−0.27	−0.12	0.00	0.08	0.16	0.23	0.04
Q12	−0.02	−0.12	**0.58**	0.12	−0.01	0.07	−0.06	0.08	−0.05
Q14	0.06	0.07	**0.46**	−0.10	0.01	−0.04	0.08	−0.26	0.05
Q15	0.02	**0.41**	0.04	−0.15	0.00	−0.09	0.08	−0.02	0.14
Q20	0.01	**0.51**	−0.03	0.03	−0.02	0.02	−0.02	0.03	0.04
Q21	−0.06	−0.31	0.05	0.12	−0.01	−0.25	−0.02	0.38	−0.14
Q22	−0.04	0.04	−0.06	−0.06	−0.07	**0.61**	−0.07	−0.01	0.05
Q24	0.15	0.12	−0.06	0.10	0.10	0.39	−0.13	0.02	−0.16
Q25	**0.46**	0.07	−0.11	0.06	−0.00	0.10	0.01	0.05	−0.03
Q26	**0.43**	−0.06	0.06	0.04	0.01	0.10	0.03	0.01	0.01
Q27	**0.48**	0.00	−0.05	0.06	0.03	0.03	−0.06	0.05	−0.02
Q28	**0.47**	−0.04	0.07	0.00	−0.05	−0.16	0.05	0.04	0.01
Q29	−0.03	0.03	0.07	−0.11	**0.59**	0.01	−0.09	0.24	0.17
Q30	0.01	−0.14	0.26	−0.02	−0.05	**0.50**	0.00	0.05	0.03
Q33	0.03	−0.03	−0.06	0.08	**0.51**	0.00	0.02	−0.26	−0.11
Q34	0.01	−0.05	−0.07	0.13	**0.51**	−0.03	0.02	−0.21	−0.11
Q38	−0.06	−0.14	−0.02	0.26	−0.09	0.14	**0.43**	−0.13	−0.02
Q41	0.02	0.00	0.05	**0.59**	0.02	−0.03	0.03	0.02	0.07
Q42	0.04	0.02	0.07	**0.58**	0.03	−0.04	−0.05	0.00	0.10
Q44	−0.01	0.09	−0.18	0.23	−0.15	0.00	−0.11	−0.03	**0.59**
Component themes	Bronchitis	Woken up by chest complaint	Chest symptoms	Nose irritation	EAA, ODTS and ABPA	Work-related chest symptoms	Mucous membrane irritation	Chronic obstructive pulmonary disease	Eczema

Table 3. Final questionnaire

Question
1. Have you ever been diagnosed by a doctor with asthma?
2. Have you ever been diagnosed by a doctor with chronic obstructive pulmonary disease?
3. Have you ever been diagnosed by a doctor with another chest problem? (ask details)
4. Have you ever been diagnosed by a doctor with eczema?
5. Have you ever been diagnosed by a doctor with hay fever?
6. Have you ever been diagnosed by a doctor with any form of allergy? (ask details)
7. Do you take medicines for asthma such as inhalers or tablets?
8. Do you smoke outside of work?
9. In the last 12 months has your chest become tight?
10. In the last 12 months have you been woken up because of chest tightness?
11. Do you only get chest tightness with colds?
12. Is your chest tightness better, the same or worse away from work?
13. In the last 12 months have you had shortness of breath when walking or at rest?
14. In the last 12 months have you been woken up because of shortness of breath?
15. Do you only get shortness of breath with colds?
16. Is your shortness of breath better, the same or worse away from work?
17. In the last 12 months have you experienced wheezing or whistling in your chest?
18. In the last 12 months have you been woken up with wheezing or whistling in your chest?
19. Do you only get chest wheezing or whistling with colds?
20. Is you wheezing or whistling better, the same or worse away from work?
21. In the last 12 months have you had a cough that has kept you awake at night?
22. Do you usually cough first thing in the morning in winter?
23. Do you usually cough at other times of the day or night in winter?
24. Do you usually bring up any phlegm from your chest when you cough?
25. Do you cough like this on most days for as much as 3 months of the year?
26. Have you ever coughed up any green plugs or brown strings?
27. Is your cough better, the same or worse away from work?
28. In the last 12 months have you had unexplained weight loss?
29. In the last 12 months have you had unexplained flu-like symptoms?
30. In the last 12 months have you had unexplained fevers?
31. In the last 12 months have you had unexplained joint or muscle aches?
32. Do you ever suffer from irritation of your eyes such as pricking, itching, burning, dryness, watering, soreness or stinging of the eyes?
33. Is/was your eye irritation better, the same or worse away from work?
34. Apart from when you have a cold, do you ever suffer from irritation of your nose such as pricking, itching, burning or a runny, dry or blocked nose?
35. Is/was your nose irritation better, the same or worse away from work?
36. Do you have, or have you ever had a rash that you attribute to work?
37. Does your rash get better, stay the same or get worse away from work?

as the former was designed to ask about possible symptoms of ABPA, whereas the latter focussed on EAA.

Several items were not reinstated following the PCA. Q35 was clinically analogous to Q33. We believed Q37 to be non-specific and of little additional clinical value. Finally, we excluded all items that assessed the presence of symptoms whilst on holiday (Q13, Q17, Q23, Q31, Q40, Q43, Q46) as these were perfectly correlated with similar questions asking about symptoms away from work, which were retained. The final 37-item questionnaire (Cronbach's α = 0.76) is shown in Table 3.

Discussion

We have developed a questionnaire that has demonstrated adequate reliability in assessing health symptoms within this UK industrial composting workforce. The questionnaire was practical to administer with all 111 participants completing it within 10 min. We expect that this instrument will be of value to the occupational health community, particularly those involved in health surveillance for at risk workers, those wishing to investigate outbreaks, or cases of possible occupational illness or using it for research purposes.

We were able to clarify misunderstandings and capture more detail about responses using an interviewer-led approach. For example, in two cases we suspected that work-related symptoms were linked to exposure to volatile organic compounds in an indoor composting hall. At a different site, we suspected one case of EAA that was later confirmed through more detailed questioning about the onset of symptoms and its improvement following a change in personal protective equipment. Accordingly, we believe this approach improved the validity of judgements made about the attribution of symptoms to work or non-work-related sources.

There are several limitations of this exploratory PCA that merit discussion. The first relates to the relatively small sample size in our study. Some authors have suggested a minimum sample of 300 participants or more with at least 5–10 observations when conducting factor analysis, an approach closely related to PCA [15]. Secondly, some authors have challenged the use of the Kaiser–Guttman criterion in which components with an eigenvalue greater than 1 are retained, raising concerns that this value may lead to miscalculations [16,17]. Nonetheless, we believe that we used appropriate statistical approaches in our analysis, which are reflective of conventional techniques used in the field.

The nine PCA components appear to broadly fit the main themes that the questionnaire was intended to cover, namely the presence of work-related mucous membrane symptoms as a potential indicator of irritation or allergy from bioaerosol exposure; work-related chest symptoms suggestive of obstructive or restrictive lung disease, and symptoms suggestive of EAA, ODTS, ABPA or dermatitis.

A third limitation is the use of 0.4 as a minimum cut-off for loading on components in this study, as well as the relatively limited number of variables that loaded onto some of the components. Although some authors suggest using this cut-off value regardless of sample size, others have recommended values of 0.6 when performing factor analyses with small sample sizes [18]. In our study, a cut-off of 0.6 would have most likely increased cross-loadings thus making interpretation of our clinical components more difficult. To this end, for the purposes of an exploratory rather than confirmatory PCA, we believe our value of 0.4 to be appropriate. Finally, the choice of questions retained in the final questionnaire following the PCA may be challenged. No questions were asked about gastrointestinal symptoms although previous research has suggested there may be an increased prevalence of such symptoms in waste workers [19]. We argue, however, that the sensitivity of such questions in distinguishing symptoms of gastro-intestinal occupational disease from non-work-related illness may be limited. Additionally, our question reduction strategy was based on perfect correlations. Another study may have found different correlations and thus produced a slightly different questionnaire to ours. Nonetheless, we believe that our use of clinical judgement in devising the final questionnaire would mitigate this to some extent.

We believe the findings from this evaluation to be a useful addition to the occupational health literature relating to the assessment of health effects from bioaerosol exposure in compost workers. In this study, both workers and management found the questionnaire to be practical, and the findings useful in informing risk assessments. Further work should examine the feasibility and acceptability of administering this questionnaire in other workforces where bioaerosol exposure is known or suspected to occur. Longitudinal studies may establish its predictive validity in identifying cases of occupational disease.

Key points

- Bioaerosol exposure is linked to several respiratory illnesses and skin complaints in workers, but it is not clear which questions to ask.
- We have created a reliable health questionnaire with nine main clinical themes, evaluated using an exploratory principal component analysis.
- The predictive value of this questionnaire in identifying cases of occupational illness should be established.

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Competing interests

None declared.

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