

Systematic Review: Occupational illness in the waste and recycling sector

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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/m³ 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 10⁴ cfu/m³ for bacteria in air and 90 EU/m³ (5 ng/m³) 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.

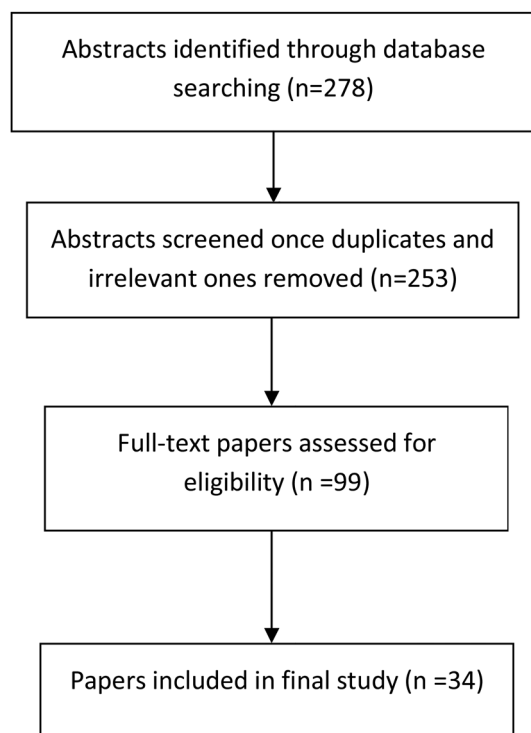


Figure 1. PRISMA flow chart for compost, municipal and hazardous waste papers.

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 (FEV₁) and FEV₁/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 pneumophila* and *Legionella long-beachae* 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 <i>et al.</i> (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 <i>et al.</i> (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 <i>et al.</i> (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 <i>et al.</i> (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 <i>et al.</i> (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 <i>et al.</i> (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 <i>et al.</i> (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 <i>et al.</i> (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 <i>et al.</i> (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 <i>et al.</i> (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)
Athanasίου <i>et al.</i> (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 <i>et al.</i> (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 <i>et al.</i> (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 <i>et al.</i> (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 <i>et al.</i> (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 <i>et al.</i> (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 <i>et al.</i> (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 <i>et al.</i> (1997) [27]	Occupational injuries	667 domestic waste collectors in Denmark	17% of employees experienced injury. Number of injuries decreased with experience	8
Hansen <i>et al.</i> (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 <i>et al.</i> (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 <i>Aspergillus fumigatus</i> ; increased IgG levels in those with high exposure to endotoxins	3
Case reports	Main findings			Quality rating
				SIGN
Alonso <i>et al.</i> (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 <i>et al.</i> (2007) [20]	3 cases of EAA in compost workers in Germany			3
Allmers <i>et al.</i> (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 rhinoconjunctivitis 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 FEV₁, non-specific bronchial hyper-reactivity and an accelerated longitudinal decline in FEV₁ 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/m³ and of airborne microorganisms, 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 chip-pings [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/m³ or fungi up to 10^6 cfu/m³. 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, bio-aerosols 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 WEEE	Organic contamination, bioaerosols Heavy manual handling, inorganic dust, PAHs, heavy metals, dioxins, furans, brominated diphenyl ethers (flame retardants)	MMI, OA, sensitization to storage mites 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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