



Review

The risky business of being an entomologist: A systematic review

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ABSTRACT

Background: Adverse work-related health outcomes are a significant problem worldwide. Entomologists, including arthropod breeders, are a unique occupational group exposed to potentially harmful arthropods, pesticides, and other more generic hazards. These exposures may place them at risk of a range of adverse work-related health outcomes.

Objectives: To determine what adverse work-related health outcomes entomologists have experienced, the incidence/prevalence of these outcomes, and what occupational management strategies have been employed by entomologists, and their effectiveness.

Methods: A systematic search of eight databases was undertaken to identify studies informing the review objectives. Data pertaining to country, year, design, work-exposure, adverse work-related health outcomes, incidence/prevalence of these outcomes, and occupational management strategies were extracted, and reported descriptively.

Discussion: Results showed entomologists experienced work-related allergies, venom reactions, infections, infestations and delusional parasitosis. These related to exposure to insects, arachnids, chilopods and entognathans, and non-arthropod exposures, e.g. arthropod feed. Few studies reported the incidence/prevalence of such conditions, or work-related management strategies utilised by entomologists. There were no studies that specifically investigated the effectiveness of potential management strategies for entomologists as a population. Indeed, critical appraisal analysis indicated poor research quality in this area, which is a significant research gap.

Conclusions: Entomologists are a diverse, unique occupational group, at risk of a range of adverse work-related health outcomes. This study represents the first systematic review of their work-related health risks. Future studies investigating the prevalence of adverse work-related health outcomes for entomologists, and the effectiveness of management strategies are warranted to decrease the disease burden of this otherwise understudied group.

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1. Introduction

Work-related injuries and illnesses are a significant problem worldwide, with a global cost of 4% gross domestic product (Takala et al., 2014). Such significant economic costs in the workplace justify investigations of occupational groups with high risks. Entomologists (an occupational group focussed on arthropods, including arthropod breeders) have particularly high work-related health risks, but no systematic review of these risks has ever been conducted. Entomologists work with arthropods in a range of settings, including laboratories, insectaries, field, and museums. Their work may involve contact with insects through breeding,

teaching, researching, preserving and displaying, forensic investigations and other activities. Entomologists may breed arthropods for research, biological pest control, bait or food for other animals, such as amphibians, resulting in exposure to arthropods themselves, as well as their feed, products (e.g. faecal matter, scales), and pesticides/repellents, all of which may lead to adverse health outcomes. Entomologists may therefore be at high risk of work-related illnesses.

Exposure to arthropods poses a range of risks (Weinstein, 2013; Weinstein and Slaney, 2008). Bites and stings from hymenoptera, spiders and scorpions, may lead to envenomation which could result in pain, or allergic reactions, even death (Weinstein, 2013). Some biting insects and arachnids, such as tsetse flies, mosquitoes, and ticks may transmit diseases, posing another risk for entomologists (Weinstein, 2013). As most arthropods attack only in self defence the interactions which entomologists have with arthropods may increase their risk of bites and stings, and therefore

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envenomation, allergic reactions and disease transmission (Weinstein, 2013). Allergic reactions, such as respiratory and skin irritation, as well as anaphylactic reactions can be caused by or exacerbated by arthropod exposure (Weinstein, 2013). This exposure may also lead to psychiatric problems, such as phobia and delusions of parasitosis (Weinstein, 2013; Weinstein and Slaney, 2008). Additionally, insect exposure may lead to infestation, which may be caused by the larvae of Diptera (myiasis; Francesconi and Lupi, 2012). Exposure to arthropods is therefore associated with a range of adverse health outcomes.

Work-related health risks to entomologists extend beyond direct arthropod exposure, and also include control agents, such as pesticides. Exposure to pesticides is associated with a range of adverse health outcomes, such as cancer (Budnik et al., 2012; Polychronakis et al., 2013; Schinasi and Leon, 2014; Van Maele-Fabry et al., 2007; Van Maele-Fabry et al., 2008), diabetes (Magliano et al., 2014), Parkinson's disease (Allen and Levy, 2013; Freire and Koifman, 2012; Greener, 2013; Van Maele-Fabry et al., 2012), impaired cognitive function (Mackenzie-Ross et al., 2013), amyotrophic lateral sclerosis (Kamel et al., 2012; Sutedja et al., 2009), and infertility (Martenies and Perry, 2013; Mehrpour et al., 2014), and parental pesticide exposure can be associated with childhood cancer (Van Maele-Fabry et al., 2010, 2013; Wigle et al., 2009). Furthermore, entomologists working in museums may be exposed to unique hazards, such as volatile fumigants. There is evidence that naphthalene, one such fumigant, has been associated with a range of adverse health outcomes in museum workers, such as dizziness, headaches, nausea, chest pains, dermatitis, sore eyes and throat, and increased salivation (Linnie, 1990). Entomologists may experience different levels of pesticide and fumigant exposure to other populations, hence the pesticide and fumigant-induced adverse work-related health outcomes experienced by entomologists also warrant attention.

Entomologists are exposed to more generic field, laboratory and office exposures such as extreme temperature, traffic accidents, solar radiation, musculoskeletal and psychosocial problems, and hazards associated with other animals, such as snakes (International Labor Organization, 2012). These may lead to a range of adverse health outcomes, from direct associations, such as skin cancer from prolonged sun exposure in field work (Bauer et al., 2011; Schmitt et al., 2011), to less tangible postural and overuse problems with intensive microscopy.

Despite the high theoretical risk of adverse work-related health outcomes for entomologists, no systematic review has been conducted to provide high level evidence of such a risk. This review has three objectives:

1. to determine what adverse work-related health outcomes entomologists have experienced,
2. to determine the incidence/prevalence of these adverse work-related health outcomes, and
3. to determine what occupational management strategies have

been employed by entomologists, and their effectiveness.

For the purposes of this review an entomologist refers to any person working with or rearing arthropods, arachnids, land snails and slugs, myriapods and earthworms, with the exception of beekeepers which have been investigated separately in a recent systematic review (Stanhope et al., in preparation).

2. Methods

This systematic review was conducted in accordance with the definition provided in the PRISMA statement, '...a review of a clearly formulated question that uses systematic and explicit methods to identify, select, and critically appraise relevant research, and to collect and analyse data from the studies that are included in the review' (Moher et al., 2009).

2.1. Identification and selection of relevant research

A systematic search was conducted in August 2014 using Medline (OvidSP) (1946–2014), Cochrane Database (1992–2014), Scopus (1995–2014), Cumulative Index to Nursing and Allied Health Literature (CINAHL) (EbscoHost) (1981–2014), Health Source (EbscoHost) (1952–2014), Academic Search Complete (EbscoHost) (1900–2014), Zoological Record (Web of Science) (1864–2014) and Web of Science Core Collection (1900–2014) databases. Search terms (see Tables 1 and 2) were searched in title, keyword and abstract (as permitted by the databases), with MeSH terms (exploded) only searched in Medline, and Cochrane. Related terms were searched, and results limited to those published in English, as permitted by the databases. No limits were applied to the year of publication.

Studies identified were exported into EndNote X6 and duplicates removed. Titles and abstracts were screened for relevance using the following exclusion criteria. We excluded any study that was not published in the English language, were peer-reviewed, or published in full-text (e.g. conference abstracts were excluded). Studies that did not report data regarding adverse work-related health outcomes relating to work as entomologists were also excluded. Adverse work-related health outcomes include any diagnosis or symptoms experienced that were associated with entomology work. Clinical findings alone were not considered adverse health outcomes, as they themselves would not impact upon the entomologist. Beekeepers and pesticide factory workers and applicators were not considered entomologists for the purposes of this review (beekeepers reviewed elsewhere; Stanhope et al., in preparation). Reviews were excluded; however reviews specific to the adverse work-related health outcomes for entomologists were retained for backwards and forwards searching. Studies investigating exposure of entomologists to potential health hazards, but not adverse work-related health outcomes; were also retained

Table 1
Search strategy for medline and cochrane.

1	*Entomologist# OR arachnologist# OR lepidopterologist# OR dipterologist# OR dipterist# OR (insect* NEAR/1 research*) OR (insect* NEAR/1 scien*) OR (work* NEAR/1 insect*) OR (rear* NEAR/1 insect*) OR (breed* NEAR/1 insect*) OR insectar* OR (lab* NEAR/1 insect*) OR (museum* NEAR/1 insect*)	Title, keyword or abstract
2	Insect# OR *entomolog* OR arachnolog* OR lepidopterolog* OR dipterolog*	Title, keyword or abstract
3	Entomology OR insects	MeSH (exploded)
4	occupation* OR workplace* OR (work* NEAR/1 relat*) OR work-related OR industrial	Title, keyword or abstract
5	Accidents, occupational OR Air pollutants, occupational OR Asthma, occupational OR Dermatitis, occupational OR Noise, occupational OR Occupational diseases OR Occupational exposure OR Occupational health OR Occupational health services OR Occupational injuries OR Psychology, industrial	MeSH (exploded)
6	health* OR safe* OR hygien* OR wellness OR injur* OR death OR fatal* OR accident* OR asthma* OR dermat* OR expos* OR hazard* OR risk* OR *pollut* OR nois* OR diseas* OR illness* OR psych* OR allerg*	Title, keyword, or abstract
7	Diseases OR mental disorders	MeSH (exploded)
COMBINED: (1 AND (6 OR 7)) OR ((2 OR 3) AND 5) OR ((2 OR 3) AND 4 AND (6 OR 7))		

*Replaces 0–1 characters, #replaces any number of characters NEAR/n indicates the words are *n* words apart in any order.

Table 2

Search strategy for all other databases.

1. *Entomologist# OR arachnologist# OR lepidopterologist# OR dipterologist# OR dipterist# OR (insect# NEAR/1 research*) OR (insect* NEAR/1 scien*) OR (work* NEAR/1 insect*) OR (rear* NEAR/1 insect*) OR (breed* NEAR/1 insect*) OR insectar** OR (lab* NEAR/1 insect*) OR (museum* NEAR/1 insect*)
 2. Insect# OR *entomolog* OR arachnolog* OR lepidopterolog* OR dipterolog*
 3. occupation* OR workplace# OR (work* NEAR/1 relat*) OR work-related OR industrial
 4. health* OR safe* OR hygien* OR wellness OR injur* OR death* OR fatal* OR accident* OR asthma* OR dermat* OR expos* OR hazard* OR risk* OR *pollut* OR nois* OR diseas* OR illness* OR psych* OR allerg*
- COMBINED: (1 AND 4) OR (2 AND 3 AND 4)

*Replaces 0–1 characters, #replaces any number of characters, NEAR/n indicates the words are n words apart in any order.

for this purpose. The full-texts of remaining studies were obtained and screened using the same criteria.

Studies already known to the authors were also considered for inclusion, based upon the criteria reported above. Reference and citation lists (accessed via Scopus, Web of Science and Google Scholar) of included studies, relevant reviews and excluded studies which reported exposure to potential health hazards but not adverse health outcomes, were screened to identify potentially relevant studies. These studies were subject to the same criteria as studies from the database searches. This process continued until no further studies were obtained. Where there was any uncertainty regarding the inclusion of a study, the opinion of second reviewer was sought.

2.2. Critical analysis of relevant research

Critical analysis of included studies was conducted only on studies informing Objectives 2 (incidence/prevalence) and 3 (occupational management) as Objective 1 deals only with the types of adverse work-related health outcomes reportedly experienced by entomologists, rather than a measure of these. Critical analysis considered both the level of evidence (i.e. the appropriateness of the study design for the type of research question asked) and potential methodological bias (i.e. quality of the study). Studies were allocated to the [Oxford Centre for Evidence-Based Medicine's \(2011\) Levels of Evidence](#). Studies of incidence/prevalence and those which reported the frequency of utilisation of various occupational management strategies and/or their perceived effectiveness were allocated according to the 'How common is the problem?' category, with methodological bias examined using The Joanna Briggs Institute Prevalence Critical Appraisal Tool ([Munn et al., 2014](#)). Clinical studies regarding the effectiveness of occupational management were allocated to the [Oxford Centre for Evidence-Based Medicine's \(2011\) Levels of Evidence](#) within the 'Does this intervention help?' category, and the assessment of methodological bias using the PEDro critical appraisal tool (higher scores indicate a lower risk of methodological bias) ([Maher et al., 2003](#)). Case studies/series were not assessed due to the inherent bias in their study designs. All appraisals were conducted independently by two authors (J.S. and P.W.), with any differences in scoring discussed between the two authors. Where disagreements could not be resolved the third author (S.C.) was consulted.

2.3. Data collection and analysis

Data were extracted from each of the included studies under the following headings: the country where the study took place (if not reported, the affiliation of the first author), the decade of the study (if not reported, the date of submission was used, or the date of publication if the submission date was not available; where the study crossed decades the most recent was reported), the sample

size, the type of work conducted and setting, the arthropod exposure, the adverse work-related health outcomes encountered, lag time for symptoms, the incidence/prevalence, the occupational management strategies used, and the effectiveness of these strategies. Data were synthesised descriptively, due to the broad range of exposures and outcomes investigated.

3. Results

A total of 7613 studies were retrieved from the database searching. Of these, 41 studies were included (see [Fig. 1](#)). Further nine studies were identified through screening reference and citation lists, with one more identified from the authors' collections. Therefore, a total of 51 unique studies was reported in this systematic review.

This review includes reports of adverse work-related health outcomes associated with entomology work dating from the 1920s. There was an increase in the published reports from the 1960s onwards, with a peak in the 1980s (see [Fig. 2](#)). The majority of studies were from Europe and North America (see [Fig. 3](#)).

Entomologists reported in the included studies worked as researchers (including assistants), sericulturists, insect-rearing workers/technicians, students, animal handlers, and museum curators. The reported entomologists worked in research units/laboratories (including rearing within the laboratory), other rearing facilities (for silk production, animal food/bait and biological pest control), field, schools, and museums (see [Appendix A](#) for details).

All included studies reported the types of adverse work-related health outcomes experienced by entomologists (Objective 1), 10 the incidence/prevalence of these outcomes (Objective 2) and 13 the occupational management of these adverse work-related health outcomes (Objective 3) (see [Table 3](#)). The types of health conditions were classified as allergy, infection, infestation and delusional parasitosis, as well as unspecified venom reactions. Venom reactions may be a toxic and/or allergic reaction. Four studies reported envenomation, however [Stern et al. \(2000\)](#), and [Roll and Schmid-Grendelmeier \(2005\)](#) reported that the entomologists in their studies were allergic to the venom, hence these have been classified as allergies. [Bush et al. \(2001\)](#) and [Isbister et al. \(2004\)](#) did not specify the type of reaction, and have therefore been classified as unspecified venom reactions. The majority of the included studies ($n=42$) addressed allergies.

Studies included in this review (informing Objectives 2–3) were Levels 1 ($n=4$) or 3 ($n=6$) (Level 1 reflecting the highest level of evidence, or the most appropriate study design for the question asked), with methodological quality classified as low ($n=7$) or moderate ($n=3$) (see [Table 4](#)).

3.1. The types of adverse work-related health outcomes

The adverse work-related health outcomes reportedly experienced by entomologists were associated with a range of insects, arachnids, chilopods and entognathans (see [Table 5](#)). The types of adverse work-related health outcomes included allergies, unspecified venom reactions, infection, infestation and delusional parasitosis. The majority of reports were from laboratory and/or rearing settings. Infestation was reported only during field work.

Infestation was reported as experienced by an entomologist following field collection of a number of arthropods via pooting, with symptoms experienced two months later ([Hurd, 1954](#)). *Micralymna brevilingue* Schiodte (Coleoptera), *Boletina birulai* (Lundstrom) (Diptera), *Isotoma olivacea* Tullberg (Collembola), and *Myrmar* spp. (Hymenoptera) passed from their left atrium of the sinus ([Hurd, 1954](#)). It was thought that the brass screen on the aspirator

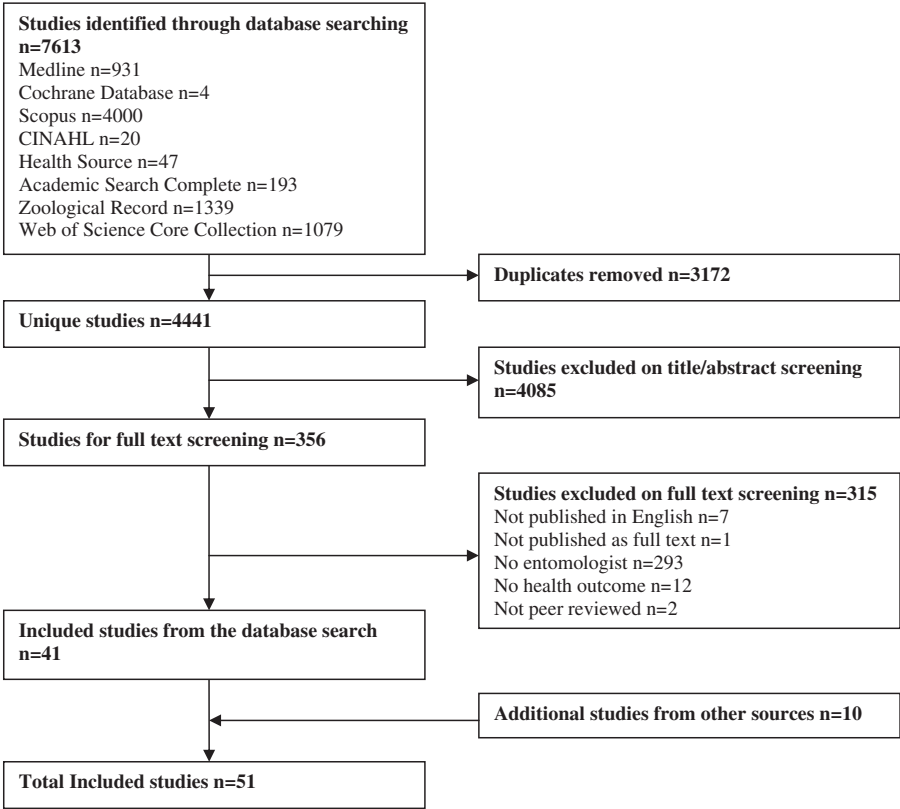


Fig. 1. Flow chart of study inclusion/exclusioncinahl: Cumulative Index to Nursing and Allied Health Literature.

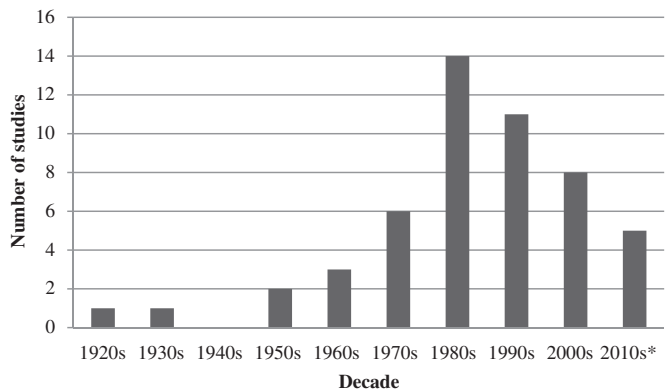


Fig. 2. The number of included studies for each decade. *note that this is 2010–2014 only, where studies crossed decades, the most recent was reported.

was inadequate to prevent the inhalation of insect eggs, which then developed within the nasal cavity (Hurd, 1954).

Traver (1951) reported her own experiences with what she concluded was scalp dermatitis due to *Dermatophagoides*. This account has been widely disputed by a number of authors (Altschuler et al., 2004; Freudenmann and Lepping, 2009; Hinkle, 2000, 2010, 2011; Shelomi, 2013a,b) and is now considered a ‘classic report’ of delusional parasitosis, or Ekbom Syndrome. Delusional parasitosis may, therefore, be experienced by entomologists, despite their interest in and understanding of arthropods.

Diptera bites have led to entomologists contracting infectious diseases. Dengue was contracted within laboratory settings following bites with infected *Aedes aegypti* (Britton et al., 2011; Ilkal et al., 1984), malaria following bites from *Anopheles stephensi* infected with *Plasmodium cynomolgi* within an insectary (Most, 1973), Zika virus following bites from *Aedes* spp. in the field (Foy

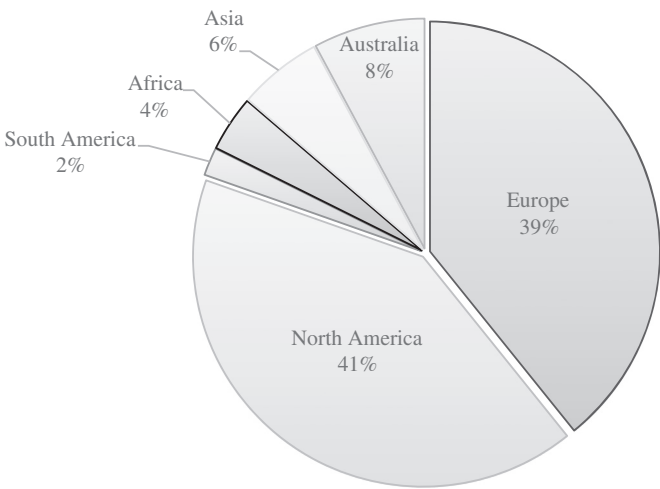


Fig. 3. Percentage of included studies in each continent.

Table 3
The number of studies informing each objective for each type of outcome.

Type of adverse health outcome	Objective 1	Objective 2	Objective 3
Allergy	42	10	12
Unspecified venom reactions	2	0	0
Infection	5	0	1
Infestation	1	0	0
Delusional parasitosis	1	0	0
Total	51	10	13

et al., 2011) and bites from *Lutzomyia* in the field resulting in infection with *Leishmania (Leishmania) mexicana* (Andrade-Narvaez et al. 2009).

Table 4

Critical appraisal scores, study designs and levels of evidence.

Study	Critical appraisal	Study design (level of evidence)
Suarthana et al. (2012)	Moderate	Cross-sectional with a non-random sample (Level 3)
Harris-Roberts et al. (2011)	Low	Cross-sectional with a consensus sample (Level 1)
Lopata et al. (2005)	Low	Cross-sectional with a non-random sample (Level 3)
Draper et al. (2003)	Low	Cross-sectional with a consensus sample (Level 1)
Siracusa et al. (2003)	Moderate	Cross-sectional with a consensus sample (Level 1)
Dyne et al. 1996	Low	Cross-sectional with a non-random sample (Level 3)
Baur and Liebers (1992)	Low	Cross-sectional with a non-random sample (Level 3)
Kaufman et al. (1989)	Low	Cross-sectional with a non-random sample (Level 3)
Burge et al. (1980)	Moderate	Cross-sectional with a consensus sample (Level 1)
Wirtz (1980)	Low	Cross-sectional with a non-random sample (Level 3)

Critical appraisal scores according to The Joanna Briggs Institute Prevalence Critical Appraisal Tool (Munn et al. 2014) with low quality indicating a score of 0–3, moderate 4–6 and high 7–10. Levels of evidence according to the Oxford Centre for Evidence Based Medicine's (2011) Levels of Evidence

Allergic reactions were associated with exposure to Coleoptera, Lepidoptera, Araneae, Blattodea, Orthoptera, Diptera, Hymenoptera, Ixodidae, Trombidiformes, Hemiptera, Isoptera, Neuroptera, Sarcoptiformes and Mesostigmata. In some cases entomologists were also allergic to the arthropod feed in addition to the arthropods they were working with (Bagenstose et al., 1980; Harris-Roberts et al., 2011), with one case reported whereby the entomologist had no allergy to the *Diabrotica* spp. with which they worked, but *Penicillium* which was within the laboratory. Furthermore, reactions following envenomation from Scorpiones, Scolopendromorpha and Hymenoptera were reported. For the cases (Roll and Schmid-Grendelmeier, 2005; Stern et al., 2000) reported regarding Hymenoptera stings the entomologists were found to be allergic to *Bombus* venom, therefore the reported reaction is assumed to be allergic, rather than toxic. For scorpions and Scolopendromorpha envenomation there was no testing regarding allergies, hence it is unclear whether these reactions were allergic and/or toxic. Reported reactions to Scolopendromorpha were pain, burning sensation, swelling, red streak, felt 'unwell', bleeding, erythema, throbbing, 'sprained' sensation, nausea, pruritus, lump, flushed feeling, and altered sensation (Bush et al., 2001), and Scorpiones reactions including pain, tingling, burning, bleeding, hypersensitivity and paraesthesia (Isbister et al., 2004). The symptoms for other allergic reactions are summarised in Table 6 where there was clinical evidence of the allergy (see Appendix A). Additionally, Wirtz (1980) reported that the

participants in their studies experienced sneezing, running nose, skin irritation, eye irritation, breathing difficulty, headache, nausea, faintness, fever, oedema, insomnia, irritability, hives, and cough, with the perceived causes reportedly Lepidoptera, Orthoptera, Hymenoptera, Coleoptera, Ixodidae, Trombidiformes, Diptera, Hemiptera, Araneae, Isoptera, Neuroptera and non-arthropod exposures. Some studies also reported anaphylactic reactions (Roll and Schmid-Grendelmeier, 2005; Stern et al., 2000; Stevens et al., 1996; Wirtz 1980). This indicates that exposure to a range of orders may result in diverse symptoms experienced by entomologists, including respiratory, ocular, and cutaneous symptoms.

Entomologists were reportedly working from a few weeks to 28 years prior to experiencing their symptoms associated with contact and/or inhalation (Bagenstose et al., 1980; Burge et al. 1980; de las Marinas et al., 2014; Frankland 1953; Kaufman et al. 1986, 1989; Lugo et al., 1994; Lunn and Hughes, 1967; Monk, 1988; Schroeckenstein et al. 1988, 1990; Sheldon and Johnston, 1941; Solley and Hyatt, 1980; Steinberg et al., 1987; Stevenson and Mathews, 1967; Tee et al., 1985; Teranishi et al., 1995), and in many instances symptoms became more severe over time (Bagenstose et al., 1980; de lasMarinas et al., 2014; Frankland, 1953; Harris-Roberts et al., 2011; Kaufman et al., 1986; Lunn and Hughes, 1967; Schroeckenstein et al. 1988, 1990; Soparkar et al., 1993; Stevenson and Mathews, 1967). In terms of bites and stings, previous occurrences had not elicited a response of the same severity (Bush et al.,

Table 5

Adverse health outcome type for each arthropod order.

	Allergy	Allergic/toxic reaction	Infection	Infestation	Delusional parasitosis
Lepidoptera	L/R NR				
Orthoptera	L/R				
Blattodea	L/R				
Coleoptera	L/R Museum			Field	
Araneae	L/R Field NR				
Mesostigmata	L/R				
Trombidiformes	L/R				
Ixodida	L/R				
Isoptera	L/R				
Hemiptera	L/R				
Neuroptera	L/R				
Sarcoptiriformes	L/R				
Diptera	L/R Field		L/R Field	Field	
Scorpiones		Field			
Scolopendromorpha		L/R NR			
Hymenoptera	L/R			Field	
Non-arthropod	L/R				
NA/not specified	L/R				NA

L/R: laboratory and/or rearing setting, NA: not applicable.

Table 6

Allergic symptoms reported for each exposure category.

	Hymenoptera	Blattodea	Diptera	Lepidoptera	Orthoptera	Coleoptera	Aranae	Sarcoptiformes	Neuroptera	Mesostigmata	Trombidiformes	Hemiptera	Non-arthropod	Not specified
Upper respiratory symptoms (rhinitis, nasalitching,nasal dryness, nasal crusting, nasalcongestion,nasal discharge,nasal obstruction,sneezing, rhinorrhea,nasal soreness, rhinoconjunctivitis, palatal itching, hayfever, sore throat, burning throat, dryness of pharynx, irritation of pharynx,itching pharynx)	•	•	•	•	•	•	•	•	○	○	○	○	○	•
Lower respiratory tract symptoms (bronchitis, asthma,pleuritic type pain, wheezing, breathing difficulties, chest tightness,cough, breathlessness,sputum production,dyspnoea, granulomatous interstitial pneumonia, hypersensitivity pneumonitis)	•	○	•	•	•	•	•	•	○	○	○	○	•	•
Ocular symptoms (irritation, conjunctivitis, pain,ocular pruritus, ocular erythema, ocular oedema,lacrima-tion, rhinoconjunctivitis)	•	•	•	•	•	•	•	•	○				○	
Cutaneous symptoms (rashes,redness, dermatitis,irritation, urticaria, wheals, flaring, papulovesicular eruptions, punctuate,papular lesions, pruritus, prickling sensation,ex-foliation, corneous skin, wrinkling, dry skin, angioedema, swelling,red papules, painful cracks in skin, tight skin)	•	○	•	•	•	•	•						○	
Other (hot flushed feeling, weight loss, decreased exercise tolerance, numbness, difficulty speaking/tongue swelling, warm feeling,	•		•	•		•	•						•	

2001; Roll and Schmid-Grendelmeier, 2005; Stern et al., 2000; Stevens et al., 1996) and Roll and Schmid-Grendelmeier (2005) reported that symptoms were exacerbated by subsequent stings.

3.2. Incidence and prevalence of adverse work-related health outcomes

Ten cross-sectional studies reported incidence or prevalence of adverse work-related health outcomes for entomologists. Meta-analysis was not possible given the range of settings, exposure and health outcomes reported. There were no reports of prevalence or incidence for the other types of adverse work-related health outcomes.

3.3. Prevalence

The prevalence of allergies in entomologists was reported in eight studies, two of which compared these with other populations. The prevalence of allergies in entomologist is reported in Table 7. The type of prevalence (e.g. lifetime, point) is unclear in all included studies.

Harris-Roberts et al. (2011) compared the prevalence of respiratory symptoms experienced by entomologists ($n=32$) working with locusts and *Tenebrio molitor*, with office workers in the same facility ($n=9$) finding no significant differences in the symptom prevalence. In contrast, Burge et al. (1980) compared the prevalence of asthma, urticaria, and rhinitis experienced by insect handlers and laboratory personnel working with locusts, having field workers with intermittent locust exposure, laboratory scientists not working with insects, and administrators, finding that symptoms were clearly most severe for the insect handlers (see Table 8).

Wirtz (1980) reported a cross-sectional survey of 84 arthropod rearing facilities with 59.5% of them reporting at least one employee with a work-associated allergy. For 75.6 of these reactions, it was believed their exposure was through airborne material, 63.5% contact, 7.8% stings, 3.5% bites, and 7.8 unknown/not reported. Of the 155 symptomatic respondents to their survey; 67.0% reported sneezing/ running nose, 33.0% breathing difficulties, 61.7% skin irritation, 60.9% eye irritation and 2.6% anaphylactic shock.

Baur and Liebers (1992) reported that of the 21 (24.71%) of entomologists they studied, who work with *Chironomidae* ($n=85$) were sensitised to *Chironomidae* haemoglobins (*Chi t* 1). Of those who were *Chi t* 1-sensitised 81.0% reported experiencing rhinitis, 76.2% bronchial asthma, 52.3% urticaria and 57.1% ocular symptoms. They were compared with 74 *Chi t* 1-sensitized individuals exposed through hobbies, revealing that entomologists who were sensitized were significantly more likely to report bronchial asthma, with no significant difference in prevalence for rhinitis, urticaria or ocular symptoms.

3.4. Incidence

Draper et al. (2003) surveyed employers of employees working with laboratory animals. The survey investigated the employees' asthma and rhinitis. For those working with insects (estimated $n=294-426$), one case of asthma was reported, representing an estimated rate of 2.35/1000/year (95% CI: 0.06–13.1), and five cases of rhinitis were reported, with an estimated rate of 21.1/1000/year (95% CI: 9.65–40.1).

The incidence of post-hire asthma amongst insect breeders ($n=157$) was reported in Suarathana et al.'s (2012) study, as 16.2/1000 person-years. They combined the data of those breeding *Lymantria dispar*, *Pectinophora gossypiella* and Tephritidae, hence this finding is not specific to Lepidoptera exposure. Suarathana et al.

palpitations, felt pre-syncope, vomiting, vertigo, nausea)

• The condition was specific to the order reported, ◦ various allergens were reported therefore unclear which exposure resulted in which symptoms.

Table 7
Prevalence of allergic reactions.

Reference	Work-setting/exposure	Allergen identified	n	Symptoms	Prevalence (%)
Harris-Roberts et al. (2011)	Working in an insectary (for animal food) rearing locusts, crickets (Orthoptera) and <i>Tenebrio molitor</i> (Coleoptera)	locusts, crickets (Orthoptera), <i>Tenebrio molitor</i> (Coleoptera) and bran	23	Respiratory symptoms Lower respiratory tract symptoms Upper respiratory tract symptoms	30 17 17
Burge et al. (1980)	Laboratory scientists and breeders working with locusts, and fieldwork researchers with some exposure to locusts (Orthoptera)	<i>Locusta migratoria</i> and <i>Schistocerca gregaria</i> (Orthoptera)	43	Asthma Rhinitis Urticaria	26 35 33
Kaufman et al. (1989)	Research centre working with <i>Lucilia cuprina</i> (Diptera)	<i>Lucilia cuprina</i> (larva and adults) (Diptera)	54	Asthma/chest tightness Rhinitis/nasal symptoms Rash Ocular	11 24 17 20
Dyne et al. (1996)	Rearing of <i>Amblyseius cucumeris</i> (Mesostigmata), <i>Phytoseiulus persimilis</i> (Mesostigmata), <i>Encarsia Formosa</i> (Hymenoptera) for biological pest control and were also exposed to <i>Tetranychus urticae</i> (Trombidiformes) and <i>Trialeurodes vaporariorum</i> (Hemiptera)	Allergy to <i>Amblyseius cucumeris</i> (Mesostigmata), <i>Phytoseiulus persimilis</i> (Mesostigmata), <i>Encarsia Formosa</i> (Hymenoptera), <i>Tetranychus urticae</i> (Trombidiformes) and <i>Trialeurodes vaporariorum</i> (Hemiptera)	26	Chest tightness, hayfever or nasal symptoms	50
Siracusa et al. (2003)	<i>Calliphora vomitoria</i> (Diptera), <i>Aphomia sociella</i> (Lepidoptera), <i>Tenebrio molitor</i> (Coleoptera) and <i>Hypopta agavis</i> (Lepidoptera) exposure through rearing, and laboratory work	<i>Calliphora vomitoria</i> (Diptera), <i>Aphomia sociella</i> (Lepidoptera), <i>Tenebrio molitor</i> (Coleoptera) and <i>Hypopta agavis</i> (Lepidoptera)	68 ^a	Respiratory, cutaneous or ocular symptoms Rhinoconjunctivitis Asthma Urticaria	9 6 3 1
Lopata et al. (2005)	Laboratory workers and scientists working with <i>Locusta migratoria</i> (Orthoptera), <i>Blattella germanica</i> (Blattodea), <i>Periplaneta Americana</i> (Blattodea), <i>Trichostetha fascicularis</i> (Coleoptera) and <i>Carausius morosus</i> (Phasmatodea)	<i>Locusta migratoria</i> (Orthoptera), <i>Blattella germanica</i> (Blattodea), <i>Periplaneta Americana</i> (Blattodea)	10	Respiratory or cutaneous Wheezing Asthma Rhinoconjunctivitis Urticaria	60 10 30 40 40

^a This study reported on fish bait retailers as well who are not considered entomologists. Therefore the review authors have calculated the prevalences based for the 68 laboratory workers and breeders

Table 8
Comparison of allergic prevalence for different workers, adapted from Burge et al. (1980).

	Laboratory insect handlers (n=43)	Field workers (n=18)	Other laboratory scientists (n=29)	Administrators (n=28)
Work-related asthma (%)	26	0	7	0
Work-related rhinitis (%)	35	6	13	7
Work-related urticaria	33	6	7	0

(2012) also reported the incidence in office workers who worked in an area separate from these rearing facilities, which was found to be 9.2/1000 person-years (no significant difference from entomologists). The incidence of post-hire asthma for those who were predominantly exposed to Lepidoptera was found to be 26.9/1000 person years, whereas those exposed predominantly to other insects had an incidence of 3.0/1000 person years (no significant difference between groups). Furthermore, Lepidoptera were identified as the main allergen in this study, supporting the notion that those working with Lepidoptera are at risk of allergy, associated with this exposure.

3.5. Occupational management of adverse work-related health outcomes

Two studies reported the existing occupational management strategies (Britton et al., 2011; Suarathana et al., 2012). Britton et al. (2011) reported a case of an entomologist who was bitten by *Aedes aegypti* infected with Dengue virus. The requirements for personal protective equipment in Australian laboratories working with Dengue virus, such as gloves, gown and eye protection were reportedly followed, however the incident still occurred. Similarly, Suarathana et al. (2012) reported that the rearing facilities they investigated in their cross-sectional study had protocols regarding sanitation, a respiratory protection programme employed and engineering controls to minimise insect exposure. Despite these

measures a high number of entomologists working in these facilities reported post-hire asthma.

A number of entomologists either transferred to other areas to minimise contact with the allergens (Frankland, 1953; Harris-Roberts et al., 2011; Kaufman et al., 1986; Lunn and Hughes, 1967; Solley and Hyatt, 1980; Tee et al., 1985), or terminated their employment (Kaufman et al., 1989; Monk, 1988; Stevenson and Mathews, 1967). In one case (Stevenson and Mathews, 1967) this was not sufficient to resolve his symptoms, as it was revealed he had worn his dirty work clothes home with him, and later he tested positive to dust from the rugs, mattress and stuffed furniture within his home, indicating that he had brought the allergens home on his clothing (Stevenson and Mathews, 1967). Wirtz (1980) reported in a cross-sectional survey that 27.8% of their respondents with allergic symptoms either left their job, or transferred to other areas, because of their symptoms.

Kaufman et al. (1989) reported in their cross-sectional study that asthma and chest tightness was either improved or eliminated by employing occupational hygiene measures. Furthermore, nine of the 12 workers who reported upper respiratory symptoms reported an elimination or significant reduction of symptoms a range of preventive measures, such as respirator use, local air extractor systems, wearing protective clothing, including a mask, and wet cleaning of cages and benches. In terms of cutaneous symptoms, applying barrier creams and wearing masks and coveralls reportedly reduced or resolved symptoms for six of the nine

Table A1
Summaries of all included studies.

Reference	Decade	Country	Work setting/exposure	Work-related health outcome
Sheldon and Johnston (1941)	1920s	USA	Museum: assistant museum curator using <i>Dermestid</i> larvae (Coleoptera) to remove flesh from specimens	Allergy: <i>Dermestid</i> (Coleoptera) Symptoms: Asthma ANS coryza
Traver (1951)	1930s	USA	Fieldwork: entomologist working with <i>Dermatophagoides</i> (Acariformes)	Dermatitis reported, but discredited. Considered delusional parasitosis (Altschuler et al. 2004; Freudenmann and Lepping 2009; Hinkle 2000, 2010, 2011; Shelomi 2013a,b)
Frankland (1953)	1940–1950s	UK	Research station/institute: breeding <i>Locusta migratoria</i> and <i>Schistocerca gregaria</i> (Orthoptera)	Allergy: <i>Locusta migratoria</i> and <i>Schistocerca gregaria</i> (Orthoptera) Symptoms: rhinitis, asthma, sneezing, catarrh, rhinorrhoea, bronchitis, sinusitis, wheezing cough, and urticaria
Hurd Jr. (1954)	1950s	USA	Fieldwork: research entomologist pooting to collect small-sized insects	Infestation with <i>Micralymna brevilangue</i> Schiodte (Coleoptera), <i>Boletina birulai</i> (Lundstrom) (Diptera), <i>Isotoma olivacea</i> Tullberg (Collembola), and <i>Mymar</i> spp. (Hymenoptera)
Herrmann (1966)	1960s	USA	Laboratory: entomologist rearing Diptera	Allergic symptoms
Lunn and Hughes (1967)	1960s	UK	Laboratory: working with <i>Sitophilus granaries</i> (Coleoptera)	Allergy: <i>Sitophilus granaries</i> (Coleoptera) Symptoms: Sneezing, urticaria, conjunctivitis and asthma
Stevenson and Mathews (1967)	1960s	USA	Bait company: rearing <i>Galleria mellonella</i> (Lepidoptera)	Allergy: adult <i>Galleria mellonella</i> , <i>Galleria</i> wings, and <i>Cecropia</i> moth (Lepidoptera) Symptoms: Rhinitis, and asthma
Cooke et al. (1973)	1970s	USA	Arachnologist working with <i>Tarantula</i> (Araneae)	Allergy: the urticating hairs of <i>Brachypelma smithi</i> (Araneae) Symptoms: skin irritation, pruritus, urticaria, and punctuate
Most (1973)	1970s	USA	Insectary: graduate student working with <i>Anopheles stephensi</i> (Diptera) infected with <i>Plasmodium cynomolgi</i>	Infected with malaria Symptoms: Fever, chills, and headache
Ratcliffe (1977)	1970s	USA	Fieldwork: working with <i>Theraphosid</i> (Araneae)	Allergy: <i>Tarantula</i> urticating hairs (Araneae) Symptoms: Papular dermatitis, prickling sensation, tight skin, oedema, itchy, red papules, wrinkling of skin, dry skin, exfoliation, numb, corneous skin, painful cracks in skin, and redness
Bagenstose et al. (1980)	1970s	USA	Laboratory: supervisor and research assistant working with amphibians, breeding crickets for feed (Orthoptera)	Allergy: <i>Acheta domestica</i> (Orthoptera), cornmeal, soybean, wheat, cricket bin dust, pervinal vitamin dust, Brewer's yeast (associated with cricket feed) Symptoms: Ocular pruritus, nasal congestion, rhinorrhea, sneezing, cough, wheezing, asthma and burning sensation in throat
Burge et al. (1980)	1970s	UK	Laboratory and fieldwork: scientists and breeders working with locusts (Orthoptera)	Allergy: <i>Locusta migratoria</i> and <i>Schistocerca gregaria</i> (Orthoptera) Symptoms: wheeze, breathlessness, urticaria, asthma, and rhinitis
Solley and Hyatt (1980)	1970s	USA	Laboratory: research entomologists working with <i>Diabrotica</i> spp. (Coleoptera)	Allergy: <i>Penicillium</i> (in the laboratory) Symptoms: chills, fever, malaise, myalgia, cough, chest tightness, decreased exercise tolerance, and two-flight dyspnoea
Wirtz (1980)	1980s	USA	Arthropod rearing	Allergies with perceived causes reported as Lepidoptera, Orthoptera, Hymenoptera, Coleoptera, Ixodida, Trombidiformes, Diptera, Hemiptera, Araneae, Isoptera, Neuroptera and non-arthropod exposures (see note ^a for details) Symptoms: sneezing/running nose, skin irritation, eye irritation, breathing difficulty, anaphylactic shock, headache, nausea, faintness, fever, oedema, insomnia, irritability, hives, and cough
Baur et al. (1982)	1980s	Germany	Insectary (for fish food) and laboratory: working with <i>Chironomid</i> larvae (Diptera)	Allergy: <i>Chironomus thummi thummi</i> hemoglobins (Diptera) Symptoms: Itching, wheal and flare, conjunctival irritation, cough, sneezing, rhinorrhea, shortness of breath and wheezing
Etkind et al. (1982)	1980s	USA	Laboratory: researchers working with <i>Lymantria dispar dispar</i> (Lepidoptera)	Allergy: <i>Lymantria dispar dispar</i> cast larval skins, whole larvae and egg mass hairs (Lepidoptera) Symptoms: Rhinitis, dyspnoea, tearing eyes, wheals and flares, rashes, itching of eyes, papular lesions, and chest tightness
Bernstein et al. (1983)	1980s	USA	Bait company: Rearing <i>Tenibrio molitor</i> larvae (Coleoptera)	Allergy: <i>Tenibrio molitor</i> exoskeletons (Coleoptera) Symptoms: Wheezing, ocular itching, dyspnoea, rhinorrhea, lacrimation, asthma, rhinitis, and urticaria
Ilkal et al. (1984)	1980s	India	Laboratory: working with <i>Aedes aegypti</i> (Diptera) which had been inoculated with serum from a patient with Dengue	Dengue infection following a bite from <i>Aedes aegypti</i> inoculated with serum from a patient with Dengue (Diptera) Symptoms: fever chills, body ache, joint pains, and headache
Tee et al. (1985)	1980s	UK	Insectary: scientific worker rearing <i>Musca domestica</i> (Diptera)	Allergy: <i>Musca domestica</i> fly dust (Diptera) Symptoms: eye irritation, sneezing, and nasal discharge
Kaufman et al. (1986)	1980s	Australia	Insectary and fieldwork: Entomologist working with <i>Lucilia cuprina</i> and <i>Chrysomya bezziana</i> (Diptera)	Allergy: <i>Lucilia cuprina</i> (and positive test for <i>Chrysomya bezziana</i> allergy, but no occupational symptoms) (Diptera) Symptoms: dryness and irritation or pharynx, rhinorrhoea, sneezing, conjunctival irritation, hot flushed feeling,

Table A1 (continued)

Reference	Decade	Country	Work setting/exposure	Work-related health outcome
Spieksma et al. (1986)	1980s	Netherlands	Laboratory: working with <i>Drosophila melanogaster</i> (Diptera)	tight chest, sore throat, and rhinitis Allergy: <i>Drosophila melanogaster</i> (Diptera) Symptoms: cough, wheezing, stuffy nose, dyspnoea, and itchy eyes
Steinberg et al. (1987)	1980s	USA	Laboratory: work with <i>Blatella germanica</i> and <i>Periplaneta americana</i> (Blattodea)	Allergy: <i>Periplaneta americana</i> (whole body, haemolymph and faecal matter), <i>Blatella germanica</i> and <i>Supella longipalpa</i> (Blattodea) Symptoms: Nasal stuffiness, runny nose, sneezing, ocular itching, and palatal itching
Monk (1988)	1980s	UK	Laboratory insectary: Biochemist working with locusts (Orthoptera)	Allergy: locusts (Orthoptera) Symptoms: Itching, redness, swelling, asthma, urticaria, and conjunctivitis
Schroeckenstein et al. (1988)	1980s	USA	Laboratory insectary: research entomologist working with many insects, including <i>Alphitobius diaperinus</i> (Coleoptera)	Allergy: <i>Alphitobius diaperinus</i> (larvae, pupae and adults) (Coleoptera) Symptoms: rhinitis, pruritus, angioedema, asthma, tongue swelling, difficulty talking, urticaria, and conjunctivitis
Tee et al. (1988)	1980s	UK	Research centre: working with locusts (Orthoptera)	Allergy: <i>Locusta migratoria</i> and <i>Schistocerca gregaria</i> (Orthoptera) Symptoms: Bronchial asthma, urticaria, and rhinitis
Kaufman et al. (1989)	1980s	Australia	Research centre: working with <i>Lucilia cuprina</i> (Diptera)	Allergy: <i>Lucilia cuprina</i> (larva and adults) (Diptera) Symptoms: Rhinitis, rashes, asthma, chest tightness, conjunctivitis, 'pleuritic' type pain, nasal obstruction, nasal itching, rhinorrhoea, sneezing, itching pharynx, nasal dryness, dry pharynx, nasal soreness, nasal crusting, ocular itching, ocular pain, ocular erythema, ocular oedema, lachrimation, urticaria, and pruritus
Nakazawa and Umegae (1990)	1980s	Japan	Sericulturist rearing <i>Bombyx mori</i> (Lepidoptera)	Allergy: <i>Bombyx mori</i> (Lepidoptera) leading to granulomatous interstitial pneumonia secondary to hypersensitivity pneumonitis Symptoms: cough, exertional dyspnoea, fever, sputum production, and weight loss
Schroeckenstein et al. (1990)	1990s	USA	High school: Animal handler with work exposure to <i>Tenebrio molitor</i> (Coleoptera)	Allergy: <i>Tenebrio molitor</i> (larva, pupa, adult) (Coleoptera), and bran (2 and 4 weeks old) associated with feed Symptoms: Rhinoconjunctivitis, and nasal congestion
Baur and Liebers (1992)	1990s	Germany	Laboratory and insectary (fish food): working with <i>Chironomidae</i> (<i>Chi t I</i>) (Diptera)	Allergy: <i>Chironomidae</i> (<i>Chi t I</i>) haemoglobin (Diptera) Symptoms: bronchial asthma, conjunctivitis, rhinitis, and urticaria
Soparkar et al. (1993)	1990s	Canada	Laboratory: university student working with <i>Melanoplus sanguinipes</i> (Orthoptera)	Allergy: <i>Melanoplus sanguinipes</i> (Orthoptera) Symptoms: urticaria, wheezing, lacrimation, shortness of breath, rhinitis, and cough
Lugo et al. (1994)	1990s	Italy	Research and rearing (biological pest control): working with <i>Chrysoperla carnea</i> (Neuroptera), <i>Leptinotarsa decemlineata</i> (Coleoptera), <i>Ostrinia nubilalis</i> (Lepidoptera) and <i>Ephestia kuehniella</i> (Lepidoptera)	Allergy: <i>Ostrinia nubilalis</i> (adults) (Lepidoptera), <i>Ephestia kuehniella</i> (eggs, adults, scales and wastes) (Lepidoptera), <i>Leptinotarsa decemlineata</i> (Coleoptera), <i>Chrysoperla carnea</i> (eggs, adult) (Neuroptera), wheat/durum wheat flour (in feed) Symptoms: Rhinoconjunctivitis, and asthma
Castro et al. (1995)	1990s	Brazil	Laboratory: working with <i>Theraphosidae</i> (Araneae)	Allergy: <i>Theraphosidae</i> urticating hair (Araneae) Symptoms: skin irritation, coryza, pruritus, urticaria, conjunctivitis, sneezing, and angioedema
Teranishi et al. (1995)	1990s	Japan	Fieldwork: researcher collecting adult <i>Chironomus plumosus</i> and <i>Tokunagayusurica akamusi</i> (Diptera) using suction tube and/or light traps	Allergy: adult <i>Chironomus plumosus</i> (Diptera) Symptoms: rhinorrhea, and sneezing
Cipolla et al. (1996)	1990s	Italy	Research and rearing (biological pest control): working with <i>Chrysoperla carnea</i> (Neuroptera), <i>Leptinotarsa decemlineata</i> (Coleoptera), <i>Ostrinia nubilalis</i> (Lepidoptera) and <i>Ephestia kuehniella</i> (Lepidoptera)	Allergy: <i>Ephestia kuehniella</i> (eggs, adults, and scales) (Lepidoptera) and <i>Chrysoperla carnea</i> (eggs) (Neuroptera) Symptoms: Asthma, conjunctivitis, and rhinitis
Dyne et al. (1996)	1990s	UK	Insectary (biological pest control): working with <i>Amblyseius cucumeris</i> (Mesostigmata), <i>Phytoseiulus persimilis</i> (Mesostigmata), <i>Encarsia Formosa</i> (Hymenoptera) and exposure to <i>Tetranychus urticae</i> (Trombidiformes) and <i>Trialeurodes vaporariorum vaporariorum</i> (Hemiptera)	Allergy: <i>Amblyseius cucumeris</i> (Mesostigmata), <i>Phytoseiulus persimilis</i> (Mesostigmata), <i>Encarsia Formosa</i> (Hymenoptera), <i>Tetranychus urticae</i> (Trombidiformes) and <i>Trialeurodes vaporariorum vaporariorum</i> (Hemiptera) Symptoms: Chest tightness, nasal symptoms, and hayfever
Stevens et al. (1996)	1990s	Belgium	Laboratory: doctoral student working with <i>Glossina morsitans</i> (Diptera), with previous exposure to <i>Glossina palpalis gambiensis</i> (Diptera)	Allergy (anaphylactic reaction) to <i>Glossina morsitans morsitans</i> (salivary gland extracts) and <i>Glossina palpalis gambiensis</i> (Diptera) Symptoms (following a <i>Glossina morsitans morsitans</i> bite): Itching, warm feeling, oedema, redness, urticaria, palpitations, and felt presyncopal
Arlian et al. (1999)	1990s	USA	Researcher working with <i>Hemisarcoptes cooremani</i> (Sarcoptiformes)	Allergy: <i>Hemisarcoptes cooremani</i> (Sarcoptiformes) Symptoms: watery eyes, and rhinitis
Stern et al. (2000)	1990s	Switzerland and Belgium	A biology student and a biologist working with <i>Bombus</i> spp. (Hymenoptera)	Allergy (anaphylactic reaction) to <i>Bombus</i> spp. venom (Hymenoptera) Symptoms after a bumblebee sting: Vertigo, nausea, rhinoconjunctivitis, angioedema, pruritus, wheezing, dyspnoea, and vomiting
Bush et al. (2001)	1990–2000s	USA	Entomologists working with <i>Scolopendra heros</i> and <i>Scolopendra subspinipes</i> (Scolopendromorpha) with bites during TV interview, class preparation, and within animal facility	Unspecified venom reaction from <i>Scolopendra heros</i> and <i>Scolopendra subspinipes</i> (Scolopendromorpha) Symptoms following bites: Pain, burning sensation, swelling, red streak, felt 'unwell', bleeding, erythema, throbbing, 'sprained' sensation, nausea, pruritus, lump, flushed, and altered sensation

Draper et al. (2003)	1990–2000s	UK	Laboratory: working with insects	Symptoms: Asthma and rhinitis
Siracusa et al. (2003)	2000s	Italy	Laboratory and insectary (bait): working with <i>Calliphora vomitoria</i> (Diptera), <i>Aphomia sociella</i> (Lepidoptera), <i>Tenebrio molitor</i> (Coleoptera) and <i>Hypopta agavis</i> (Lepidoptera)	Allergy: <i>Calliphora vomitoria</i> (Diptera), <i>Aphomia sociella</i> (Lepidoptera), <i>Tenebrio molitor</i> (Coleoptera) and <i>Hypopta agavis</i> (Lepidoptera) Symptoms: Asthma, urticaria, and rhinoconjunctivitis
Isbister et al. (2004)	1990–2000s	Australia	Fieldwork: exposure to <i>Urodacus planimanus</i> and <i>Lychas bucharia</i> (Scorpiones)	Unspecified venom reaction from <i>Urodacus planimanus</i> and <i>Lychas bucharia</i> (Scorpiones) Symptoms: pain, tingling, burning, bleeding, hypersensitive, and paraesthesia
Vega et al. (2004)	1990–2000s	Spain	Entomologist exposed to <i>Thaumetopoea pityocampa</i> (Lepidoptera)	Allergy: <i>Thaumetopoea pityocampa</i> (Lepidoptera) Symptoms: Urticaria
Lopata et al. (2005)	2000s	South Africa	Laboratory: laboratory workers and scientists working with <i>Locusta migratoria</i> (Orthoptera), <i>Blattella germanica</i> (Blattodea), <i>Periplaneta americana</i> (Blattodea), <i>Trichostetha fascicularis</i> (Coleoptera) and <i>Carausius morosus</i> (Phasmatodea)	Allergy: <i>Locusta migratoria</i> (Orthoptera), <i>Blattella germanica</i> (Blattodea), <i>Periplaneta americana</i> (Blattodea) Symptoms: Urticaria, rhinitis, asthma, rhinoconjunctivitis, and wheezing
Roll and Schmid-Grendelmeyer (2005)	2000s	Switzerland	Biologist working with <i>Bombus terrestris</i> (Hymenoptera)	Allergy (anaphylactic reaction) to <i>Bombus</i> spp. venom (Hymenoptera) Symptoms: Swelling, asthma, urticaria, and Quinke oedema
Andrade-Narvaez et al. (2009)	2000s	Mexico	Fieldwork: biology students collecting <i>Lutzomyias</i> (Diptera)	<i>Leishmania (Leishmania) mexicana</i> infection, following bites from <i>Lutzomyias</i> (Diptera)
Britton et al. (2011)	2010s	Australia	Laboratory: scientist working <i>Aedes aegypti</i> (Diptera) infected with Dengue	Dengue virus following a bite from <i>Aedes aegypti</i> (Diptera) infected with Dengue Symptoms: fine, macular, blanching rash, pruritus, and fever
Harris-Roberts et al. (2011)	2010s	UK	Insectary (animal food): rearing locusts, crickets (Orthoptera) and <i>Tenebrio molitor</i> (Coleoptera)	Allergy: locusts, crickets (Orthoptera), <i>Tenebrio molitor</i> (Coleoptera) and bran
Foy et al. (2011)	2010s	Senegal	Fieldwork: scientists collecting <i>Aedes</i> spp.	Symptoms: upper respiratory symptoms, and lower respiratory symptoms Zika virus infection following bites from <i>Aedes</i> spp. Symptoms: fatigue, swelling, maculopapular rash, light-headedness, arthralgia, chills, dysuria, perineal pain, headache, aphthous ulcers, and hematospermia
Suarthana et al. (2012)	2010s	USA	Insectary: rearing <i>Lymantria dispar</i> (Lepidoptera), <i>Pectinophora gossypiella</i> (Lepidoptera), and <i>Tephritidae</i> (Diptera)	Allergy: Lepidoptera Symptoms: asthma
de lasMarinas et al. (2014)	2010s	Spain	Insectary: rearing <i>Ceratitis capitata</i> (Diptera)	Allergy: <i>Ceratitis capitata</i> (Diptera) Symptoms: cough, rhinoconjunctivitis, wheezing, dyspnoea, nasal discharge, sneezing, and nasal congestion

^a *Lymantria dispar*, *Manduca sexta*, *Heliothis virescens*, *Orgyia psudotsugata*, *Pectinophora gossypiella*, *Bombyx mori*, *Galleria mellonella*, *Heliothis zea*, *Malacosoma disstria*, *Hyalophora cecropia*, Moths (unspecified), *Callosamia promethea*, *Cynthia cardui*, *Diatraea gradiosella*, *Malacosoma americanum*, *Ostrinia nubilalis*, *Spodoptera eridania*, *Spodoptera frugiperda*, *Periplaneta Americana*, *Blattella germanica*, *Locusta migratoria*, *Blaberidae*, *Blattellidae*, cockroaches, *Leucophaea maderae*, *Nauphoeta cinerea*, *Supella longipalpa*, *Melanoplus differentialis*, *Apismelligera*, *Solenopsis invicta*, *Diprion similis*, *Vespidae* (unspecified), *Anthonomus grandis grandis*, *Hypera postica*, *Dermestids*, *Attagenus* spp., *Diabrotica undecimpunctata howardi*, *Diabrotica virgifera*, *Epilachna varicestis*, *Tenebrio molito*, *Tribolium* spp., *Tetranychus urticae*, *Mites* (unspecified), *Ornithodoros hermsi*, *Ornithodoros parkeri*, *Ornithonyssus bacoti*, *Aedes* spp., *Aedes aegypti*, *Culex* spp., *Culex tarsalis*, mosquitoes, *Musca domestica*, *Phormia regina*, *Sarcophaga crassipalpis*, *sarcophagidae*, *Oncopeltus fasciatus*, *Rhodnius prolixus*, *Triatomia dimidiata*, *Theraphosidae*, *Termites*, *Ascalaphidae*, Artificial diets, host plants, guinea pigs, rabbits, rodents, spider silk, haemolymph/tissues, arthropoda (unspecified).

entomologists who had reported these symptoms.

Wearing masks (Kaufman et al., 1986; Solley and Hyatt, 1980) and other forms of protective clothing (Monk 1988) reportedly helped in some cases. In a case reported by Bagenstose et al. (1980) it is unclear whether wearing a Martindale mask reduced the entomologist's symptoms; however it did not control his asthma.

In Wirtz's (1980) study of the 50 institutions where allergies were reported, 25.5% of individuals reportedly used protective equipment on a 'routine' basis, and 'as needed' 60.4% of the time, in contrast with the institutions not reporting symptoms, where workers only used such equipment routinely 9.4% of the time and 'as needed' 50.0% of the time. For those working at institutions reporting worker allergies, this equipment was respirators/masks (36.8%), gloves (35.5%), head nets (14.5%) and other equipment including exhaust hoods and clothing (13.2%). It is unclear whether the denominator for these percentages was institutions, individuals or a measure of time.

4. Discussion

To our knowledge, this is the first systematic review to investigate the adverse work-related health outcomes for entomologists. We identified 51 studies which reported adverse work-related health outcomes associated with working as an entomologist; 10 reported the incidence/prevalence and 13 occupational management. The studies reported allergies, infections, unspecified venom reaction, infestation and delusional parasitosis, following exposure to a wide range of taxa.

The spike in relevant publications in the 1980s may reflect an increased interest in occupational health and safety issues from a research and publication perspective, an increase in the number of publications and/or an increase in database indexing of publications. The decline in the number of studies in the 1990s and 2000s, however, is in contrast with the overall trend of occupational health and safety studies, which has continued to rise. This decline may be due to the large number of case studies published, which require a novel aspect if they are to be accepted for publication. Over time the likelihood of coming across a unique presentation that has not previously been described decreases, thus leading to a decrease in these case studies, and therefore the number of studies overall. Furthermore, changes in work structure have meant that entomologists do not represent the same clearly defined professional group they once did, with many working as biologists, working with a range of animals, not just arthropods, and thereby limiting the ability of researchers to investigate entomologists specifically. This may also explain why the incidence/prevalence studies were commonly investigating those working in rearing facilities, rather than those in laboratory settings or performing fieldwork, as this sub-population is more clearly defined.

In most cases, the allergens were from the insect with which they worked; however there were two reports of entomologists being allergic to arthropod feed, in addition to the arthropods with which they worked (Bagenstose et al., 1980; Harris-Roberts et al., 2011), and another case in which the entomologist had no allergy to the *Diabrotica* spp. they were working with, but *Penicillium* which was within the laboratory (Solley and Hyatt, 1980). Interestingly, most stings and bites occurred during field work, whilst most contact/inhalation allergies occurred in laboratory settings. This may indicate that different risks are present in these settings. It is acknowledged that many entomologists would be likely to work across a range of settings, as was evident in some of the studies (Bush et al., 2001; Kaufman et al., 1986, 1989).

In addition to allergies, we found reports of entomologists experiencing unspecified venom reactions, infections, infestations

and delusional parasitosis. Because these were all case studies or case series reports, we cannot determine whether entomologists are at a higher risk of these conditions in comparison with the general public. Whilst their exposure to arthropods is likely higher than other groups, they presumably have a better understanding of how to safely work with arthropods, and may therefore have a reduced risk of experiencing adverse health outcomes. For instance, Britton et al. (2011) reported a case of Dengue virus contracted by an entomologist working with *Aedes aegypti* infected with the virus. The scientist involved was reportedly following the requirements for personal protective equipment when working with Dengue virus in Australian laboratories. This indicates that despite protective practices being used, entomologists working in such situations may still be at risk of harm.

Similarly, Traver's (1951) report of what she believed to be scalp dermatitis due to *Dermatophagoides* has been deemed by many authors (Altschuler et al., 2004; Freudenmann and Lepping, 2009; Hinkle, 2000, 2010, 2011; Shelomi 2013a,b) to be delusional parasitosis, or Ekbohm Syndrome. Delusional parasitosis is generally considered rare within the psychiatric literature; however it has been estimated by entomologists to affect over 100,000 people in America (Hinkle, 2011). This disparity may be due to the reluctance of individuals to seek medical assessment, leading to under-reporting (Hinkle, 2011). Traver's (1951) report indicates that even those who presumably are at low risk of delusional parasitosis due to their experience in working with arthropods, may still experience such delusions.

Entomologists may also be asked to identify 'specimens' from those experiencing delusional parasitosis, and one would expect that they may be subjected to negative and possibly violent reactions when failing to do so. However, no such instances have been reported in the literature.

The quality of most of the studies reporting the incidence or prevalence of adverse health outcomes for entomologists was low. As such, although a number of studies report a high prevalence of work-related allergies, the finding needs to be considered in light of the potential bias introduced by the poor methodological quality of the included studies.

Studies comparing the incidence or prevalence of allergic reactions in entomologists versus others produced mixed results. This, in addition to the poor methodological quality of the included studies, limits our ability to determine whether entomologists are at increased risk of allergy or sensitization due to increased exposure to allergens, when compared with the general population. On the other hand, due to workplace occupational and safety policies, entomologists may be better equipped to protect themselves against excessive exposure to allergens, and therefore have a decreased risk of allergy when compared to the unprotected, general public. Furthermore, those with known allergies to insects are unlikely to enter the field of entomology, and workers and students who experience allergies may cease working in the field, as evident in some of the studies included in this review (Kaufman et al., 1989; Monk, 1988; Stevenson and Mathews, 1967); hence cross-sectional designs, as were used in the studies included in this review, are susceptible to 'healthy worker bias', which may under-estimate the extent of the problem. Additionally, the two studies comparing entomologists with other populations (Burge et al., 1980; Harris-Roberts et al., 2011) investigated only the presence of allergies, not the frequency, severity, or impact of the allergic reaction; hence these comparisons do not provide an in-depth analysis of the problem.

Although we cannot conclusively state that entomologists are at increased risk of symptoms associated with arthropod exposure based on the published literature, we have established that they are reported as experiencing allergic reactions, and other adverse health outcomes associated with working with a range of taxa, and

common sense dictates that their ability to avoid such exposure is diminished. It is therefore reasonable to conclude that they are likely at greater risk. Therefore, even when entomologists do not experience symptoms, it is important that appropriate occupational management strategies be employed to avoid sensitisation, and future allergic reactions. As was reported in a number of studies in this review, it could take weeks to 28 years for symptoms to appear (Bagenstose et al., 1980; Frankland, 1953; Kaufman et al., 1986, 1989; Lugo et al., 1994; Lunn and Hughes, 1967; Monk, 1988; Schroeckenstein et al., 1988; Solley and Hyatt, 1980; Steinberg et al., 1987; Stevenson and Mathews, 1967; Tee et al., 1985), and in many cases symptoms increased over time (Bagenstose et al., 1980; Harris-Roberts et al., 2011; Frankland, 1953; Kaufman et al., 1986; Lunn and Hughes, 1967; Schroeckenstein et al., 1988; Soparkar et al., 1993; Stevenson and Mathews, 1967) or with subsequent stings/bites (Bush et al., 2001; Roll and Schmid-Grendelmeier, 2005; Stern et al., 2000; Stevens et al., 1996), indicating that sensitisation had occurred.

Kaufmann et al.'s (1989) observational, cross-sectional study revealed promising findings regarding the implementation of various occupational management strategies including protective clothing, using respirators and local air extractor systems. Seabrook et al. (1985) and Davis and Jenkins (1995) reported that the use of air-filters reduced Lepidoptera scales and other debris, and thereby the risk of allergic reactions for those working in that environment. Guidelines for protecting workers against adverse work-related health outcomes such as asthma (Baur et al., 2012; Fishwick et al., 2012) and dermatitis (Nicholson et al., 2010) should be considered by entomologists and their employers to reduce the disease burden within this population, despite not being specific to the profession.

As reported in a number of studies, many entomologists had to leave their jobs (Kaufman et al., 1989; Monk, 1988; Stevenson and Mathews, 1967) or change their roles to avoid exposure to allergens (Harris-Roberts et al., 2011; Kaufman et al., 1986; Lunn and Hughes, 1967; Solley and Hyatt, 1980; Tee et al., 1985). The willingness of entomologists to do this may be influenced by their role. For instance, those involved solely in rearing facilities are unlikely to have the same investment in their career, as a scientist who has devoted significant time to studying a particularly species, which they have developed an allergy, potentially over a long duration of time.

Despite the theoretical risks of solar radiation, fumigant and pesticide exposure, motor vehicle accidents, as well as musculoskeletal disorders due to lifting, prolonged sitting and/or poor postures (International Labor Organization, 2012; Linnie, 1990), we found no studies which reported these adverse work-related health outcomes for entomologists. The absence of such reports from the literature does not discount these potential risks, but is more likely to reflect that research specific to entomologists has not been conducted, because these may be considered generic risks which are experienced in a range of occupations. The International Hazard Datasheets on Occupation for Entomologists (International Labor Organization, 2012) addresses these more generic risks, recommending that entomologists wear clothing appropriate for the conditions of their work (e.g. environment, animals, and type of work) including a hat, and non-slip shoes, use personal protective equipment such as gloves and insect-repellent, drinking water during field work, follow safety rules and regulations, be aware of the properties and protection measures of hazardous materials handled, follow manufacturer's data sheets and legal requirements, follow hygiene rules whilst eating, and use correct lifting techniques. These datasheets are not researched, nor published in a peer-reviewed journal. They do, however, provide sound, common-sense advice for entomologists.

An important finding from our review was that there were few

studies ($n=10$) investigating the prevalence/incidence of adverse work-related health outcomes for entomologists, and only four of these studies considered Level 1 evidence, suggesting that there is a need for high-level, good quality research in the area. Furthermore, there are likely to be many outcomes, such as musculoskeletal conditions, or outcomes resulting from pesticide exposure, that remain unexplored. Additionally, the effectiveness of occupational management strategies, particularly in prevention of adverse health outcomes, requires experimental research to guide occupational health and safety policies for employers of entomologists.

Large scale studies investigating the frequency of adverse health outcomes are required that extend beyond allergies, to also include stings/bites, infections, psychological/psychiatric conditions, and infestation, as well as more generic health conditions, including motor vehicle accidents, and neurological or musculoskeletal conditions. Such research should also investigate the impact of these adverse health outcomes on the individuals and the organisations that employ them, as well as current practices regarding workplace health and safety. Research in this area would allow targeted interventions to be developed to minimise the risk of adverse work-related health outcomes in entomologists, thereby reducing their disease burden.

5. Conclusion

Entomologists are at risk of allergic reactions, reactions to arthropod venom, infestations, delusional parasitosis and infections relating to their work. The risks relate to a range of taxa, and result in a diversity of respiratory, cutaneous, ocular and systemic symptoms, which may lead to discontinuation of employment. Allergic reactions may appear after weeks or decades of exposure to allergens; hence entomologists with no or few symptoms are not refractory to future symptoms, which may be severe upon onset. There are no studies that have specifically investigated the effectiveness of potential occupational management strategies for entomologists as a population. Future studies investigating the prevalence of adverse work-related health outcomes for this population, and the effectiveness of occupational management strategies are warranted, to decrease the disease burden of this otherwise understudied group.

Conflict of interest

The authors report that there were no financial conflicts of interest.

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Appendix A

See Table A1

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