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Review

30 years of samples submitted to an Australian Medical Entomology Department

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Abstract Arthropods are the cause of considerable human morbidity. In spite of numerous text books and reviews published on arthropods of medical importance, this is the first paper in the world to present a comprehensive review of specimens sent to a medical entomology laboratory over an extended period. The Department of Medical Entomology at Westmead Hospital is the New South Wales reference laboratory for arthropods of medical importance. In the years 1988–2017, there were 5655 samples submitted for identification. Some 25 orders, 188 families and 177 different genera were recorded, with 170 unique species. The most common specimens included the Australian paralysis tick *Ixodes holocyclus* (708 specimens submitted), the bird mite *Ornithonyssus bursa* (506), bed bugs *Cimex* spp. (149), moth flies *Clogmia* spp. (135), head lice *Pediculus capitis* (105), pubic lice *Pthirus pubis* (91) and scabies *Sarcoptes scabiei* (57). In 1211 samples submitted, there was no evidence for any life stages of arthropods. For these common samples, data analysed included yearly and seasonal trends, female vs. male patient submissions and the age classes of the patients. Some species such as *I. holocyclus*, *O. bursa*, *Cimex* spp., *Clogmia* spp. and *P. capitis* demonstrated strong seasonal trends. In the case of the female vs. male patients, there were significant differences in submissions with *O. bursa*, *P. capitis*, *P. pubis* and with the samples containing no arthropod evidence. Of these, only with *P. pubis* did more males submit than females. Younger ages classes (<10 years) were more associated with *I. holocyclus* and *P. capitis*, older patients >70 years) with scabies, mature females (50–69 years) with samples containing no evidence of arthropods and middle-aged adults (40–69) with the remainder of the common samples. Key diagnostic features are included for some of the more challenging arthropod species to distinguish and as well as case studies provided of situations involving unique or unusual infestations. The data provides useful information on the risks that arthropods of medical importance pose to the community and will refine educational programs.

Key words arthropod trend, bed bug, lice, mite, moth fly, scabies, tick.

INTRODUCTION

Arthropods of medical importance are the cause of considerable human morbidity. They may impact through disease transmission, via inducing allergic responses, through nuisance pest biting, by infesting the home and body, or by causing a life-threatening envenomation via bites and stings. They can also cause food spoilage and even be responsible for initiating a debilitating psychological illness.

Of all the arthropods, mosquitoes and the diseases they transmit pose the greatest threat to human health. Australia has a range of endemic arboviruses that produce thousands of disease cases annually from across all states, with the occasional outbreak (Australian Government Department of Health 2019a, 2019b; Brokenshire *et al*. 2000; Cashman *et al*. 2008; Coffey *et al*. 2014; Doggett & Russell 2005; Frost *et al*. 2012; Huang *et al*. 2016; Jansen *et al*. 2019; Knope *et al*. 2014, 2016a, 2016b, 2019; Russell & Dwyer 2000; Toi *et al*. 2017; Williams *et al*. 2015). Within Australia, there are over 30 species of mosquito that are recognised as potential vectors capable of transmitting viral pathogens such as Ross River, Barmah Forest, Murray Valley encephalitis, dengue and Kunjin viruses, as well as malaria and dog heartworm (Russell 1993). Vector mosquito species occur in almost all locations of Australia, where they can transmit a range of these pathogens. Other vector-borne diseases are those transmitted by ticks and mites, including Queensland tick typhus *Rickettsia australis* and Flinders Island spotted fever *Rickettsia honei* (both transmitted by ticks; Doggett 2004), and scrub typhus *Orientia tsutsugamushi*, transmitted by mites (Russell *et al*. 2013). None of these three diseases are notifiable, which means that statistics on case numbers are not recorded by health departments; thus, the frequency of these conditions is unknown.

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Beyond the vector-borne diseases that are transmitted biologically, medically important arthropods can impinge on human health in numerous ways. Certain insects, such as some flies, are known to mechanically transmit pathogens that can lead to food contamination and eye infections (Mallis 2004; Russell *et al*. 2013). The biting and subsequent injection of saliva from several arthropod species may result in a variety of cutaneous reactions, from a simple punctum at the bite site, to the development of papules, wheals and bullous eruptions (Doggett *et al*. 2012; Hwang *et al*. 2018). In some cases, patients can be misdiagnosed with dermatological conditions if the arthropod cause is not recognised (Nagaratnam *et al*. 2019). Occasionally, severe systemic reactions may follow a bite (Minocha *et al*. 2017) and even anaphylaxis (Doggett *et al*. 2012; Doggett & Russell 2009; Hwang *et al*. 2018). Australia has seasonal fluctuations of biting insects, such as mosquitoes and many other species of fly, especially in the warmer months of the year, and the bite alone from these pests can impede our outdoor activities.

Envenomation following injection with a toxin via a bite or sting occurs with numerous groups including spiders, ticks, Hymenoptera and several other arthropods, which are known to occasionally result in anaphylaxis and even death (Brown & Hamilton 1998; Doggett 2004; Mullins *et al*. 2016; Rappo *et al*. 2013; van Nunen 2015, 2018). Affected patients may require administration of antihistamines and other supportive medical treatment, and those with known anaphylaxis may need to carry an EpiPen® with them at all times. Australia has some of the most dangerous species of spiders in the world, and medical intervention must be sought when a bite is inflicted by the more well-known venomous species including funnel web, mouse, red back and trapdoor species. Stings from scorpions and bites from centipedes can be dangerous especially to the young, sick or elderly (Lee 1975).

One of the more unusual syndromes as the result of an arthropod bite is known as 'mammalian meat allergy'. This was first recognised as being associated with the Australian paralysis tick *Ixodes holocyclus* and occurs when a carbohydrate, oligosaccharide galactose-α-1,3-galactose (generally shortened to 'α-Gal'), is passed to humans during the tick bite (van Nunen 2015, 2018; van Nunen *et al*. 2009). This may result in the development of a sensitisation that can lead to various allergic responses following the consumption of mammalian meats. Recently, it has been shown that α-Gal sensitisation has been associated with coronary artery disease (Wilson *et al*. 2018).

Some hairy caterpillars (as well as some Lepidopteran pupae and adults) are well known to produce urticarial reactions such as contact dermatitis (Balit *et al*. 2001, 2003, 2004; Scholz *et al*. 1993). However, contact dermatitis has been associated with many other insects including psocids and carpet beetle larvae and even the chitinous exoskeleton of insects in general (Ahmed *et al*. 1981; Turner *et al*. 1996). The allergens from a variety of insects in the home can trigger respiratory issues such as asthma (Doggett *et al*. 2012, 2018b; Doggett & Geary 2014; Doggett & Russell 2009; Russell 2001). Insects including some rove beetles release irritating liquids that may produce chemical-like burns and bullous eruptions (Banney *et al*. 2000).

The presence of an insect infestation can pose enormous mental health stress (Doggett *et al*. 2012; Doggett & Russell 2009), and if there are pre-existing underlying mental health conditions, suicide can be an unfortunate outcome (Perron *et al*. 2018). Even if an infestation has been eradicated or none existed in the first place, the belief that an infestation is present can result in serious mental health impacts often leading patients to undertake extreme measures to rid themselves of the perceived infestation (Hinkle 2010, 2011; Le & Gonski 2003; Potter 1997; Slaughter *et al*. 1998). In some cases, people have applied so much insecticide, death has ensued (Doggett 2018b). The presence of an infestation from insects such as head lice and bed bugs is seen by the majority of the population as being a serious social stigma, and afflicted people often feel dirty and ashamed (Perron *et al*. 2018). Similarly, other arthropod infestations in a person's home can have a catastrophic effect on an individual's well-being.

Bed bugs can occur in such vast numbers that blood loss can lead to anaemia and even death (Doggett 2018b). These insects can also cause severe sleep loss and even have affected the operation of medical and public services when such locations become infested (Doggett 2018b). Infestations can occur wherever people frequent, from the home and hotel (Cain 2018; Miller 2018), to healthcare facilities (Doggett 2018c; Munoz-Price *et al*. 2012), public transport such as on planes (Juson & Juson 2018), trains and cruise ships (Lilly & Jones 2018), schools, offices and even in retail stores (Doggett *et al*. 2018b). The resurgence of *Cimex* spp. has been a huge financial impost and is costing the world economy billions of dollars (Doggett *et al*. 2018c). Furthermore, litigation involving this insect is on the rise, and multi-million dollar payouts have been awarded by courts (Cains *et al*. 2018; Lipman & Miller 2018).

For the most part, medically important arthropods are well known and numerous text books and reviews have been published on these pests (e.g. Bowles *et al*. 2018; Doggett *et al*. 2018a; Goddard 1993, 2000, 2013; Kettle 1995; Lee 1975; Mathison & Pritt 2014; Mullen & Durden 2002; Russell 1987, 1996, 2001; Russell *et al*. 2013; Service 1980; Smith 1973; Webb *et al*. 2013). In spite of this wealth of information, to date, no laboratory anywhere in the world has compiled a list of the medically important arthropods submitted to their facility over an extended period. The compilation and analysis of such information would provide an indication of the relative importance of such pests to a region and determine which and when specific arthropods represent the greatest risk to the community. Such information could then be used to more effectively drive public health campaigns to mitigate against these pest species and the information derived could help direct research priorities.

The Department of Medical Entomology was established in 1987 within the Institute of Clinical Pathology and Medical Research on the campus at Westmead Hospital. This occurred after the closure of the School of Public Health and Tropical Medicine (SPHTM) at the University of Sydney in 1986, which had the only medical entomology laboratory in NSW and was the national reference laboratory for insects of public health importance. Authors MJG and RCR were both employed by the SPHTM at the time of the closure and established the new facility at Westmead Hospital. The Department successfully transitioned into the hospital and pathology environment and is now the NSW state reference laboratory for the identification of arthropods of medical entomology. This paper documents the entomological specimens received over 30 years from 1988 to 2017. The year 1988 was selected, as it was the first full calendar year of data. For the more frequent specimens, data were analysed based on yearly and monthly submissions. Submissions by female vs. male patients were compared, along with the age class of the patients from whom the specimens were derived. In addition to these trends, new records of arthropod pests for Australia are highlighted, along with a list of those that were identified as being exotic. In compiling such a vast quantity of data over many years, it was possible to recognise which pests are frequently misidentified. Thus, key diagnostic features are provided to morphologically identify certain species that are challenging to distinguish. Furthermore, previously unpublished related case studies are detailed in the Supporting Information that highlight some of these diagnostic challenges and to relate unusual pest occurrences. Both the benefits and limitations of providing a public reference laboratory are examined.

MATERIALS AND METHODS

Specimen source

The majority of arthropod samples are provided by health professionals and pathology services from within NSW. However, numerous specimens have been received from interstate. Beyond these, samples were sent from environmental health officers, pest control companies, veterinarians, schools, various government and industry organisations, and members of the public.

Specimen processing

On receipt of a sample, arthropods are immediately placed in 80% ethanol to preserve taxonomic features and to avoid desiccation. Arthropod specimens are initially examined with a stereomicroscope to determine the identification with the aid of taxonomic keys when required, which are listed in Table 1.

Uncommon Acarina specimens are placed directly into a mounting media such as Euparal (originally purchased from Australian Entomological Supplies, although no longer available), or Heinz (made from a recipe listed on https://www.jiscmail.ac.uk/cgi-bin/webadmin?A2=TARDIGRADA;877e6d60.00), on a glass slide for later identification. The mounted specimen is then incubated in an oven at 45°C overnight, to allow the specimen to clear in order to reveal key taxonomic features. Acarina slide preparations are identified with the aid of a compound microscope and relevant taxonomic keys, detailed in Table 1. In rare situations involving new mite species, external experts are consulted to confirm putative identifications.

When live specimens of the immature stages of dipteran species are supplied, several of the specimens are bred through to adults to confirm the tentative identification.

All medically important specimens are identified to species. The degree of identification for specimens that have no known medical significance was classified to family, unless a specific identification is required for legal or other requirement.

Retention of specimens

Each specimen is kept with its original packaging within the Department and labelled with the date on which it was received and the patient's or client's name. The specimens are stored for 6 months prior to disposal via the hospital contaminated waste system. This retention period is in line with national guidelines for pathology samples (NPAAC 2018). Specimens were retained by the Department for curation purposes if they meet certain criteria, including those that were rare or uncommon, had a unique medical history attached to the specimen, were in good condition and would prove useful as archival material, could be used for teaching purposes, or could be used in legal proceedings.

Report handling

Once an accurate identification is established on the submitted sample, a report is issued, which details the identification when a specimen is deemed medically important. Information on the biology of the arthropod and advice on control is given, where applicable. In instances where common household arthropods are identified, the report will state 'no evidence for any life stage of medically important arthropods was identified'. At Westmead Hospital, all pathology samples are logged into a laboratory information system for recording and reporting of results. All records were exported into Microsoft Excel in order to conduct the analyses.

Data analyses

Analyses were conducted on data covering specimens submitted during the years of 1988–2017. Where there were more than 50 specimens received for any one group, the following parameters were plotted via Microsoft Excel: submissions by year, submissions by month, female vs. male patients and age class of patients (in 10 year intervals). For the age classes, the actual number of specimens was adjusted to take into account the different population numbers for each age group, to remove age-related bias. This was done by obtaining population data from the 2016 Australian census (https://profile.id.com.au/australia/five-year-age-groups), and the proportion of each age group was calculated from the overall population at the time. Age-adjusted data provide a more accurate picture of the relative risk to a particular age group. Both the actual number and population-adjusted data were graphed together. Thus, four graphs were produced for each specimen class. These plots were produced for the following specimens; the Australian paralysis tick (*I. holocyclus*), bird mites (*Ornithonyssus bursa*), moth flies (*Clogmia* spp.), bed bugs (*Cimex* spp.), head lice (*Pediculus capitis*), pubic lice (*Pthirus pubis*) and scabies mites (*Sarcoptes scabiei*). Plots were also produced of all specimens, and samples that were submitted for scabies analysis which contained no scabies mites, and samples that contained no evidence of medically important arthropods. For the latter, the age classes (in 10 year intervals) were

Table 1 Taxonomic references used for the preparation and identification of specimens, and for guidance on delusionary parasitosis.

Arthropod group	References
General Arthropoda	CSIRO (1991); Ebeling (1975); Gerozisis and Hadlington (1995); Gerozisis *et al*. (2008); Goddard (2013); Munro (1996); Russell *et al*. (2013); Upton and Mantle (2010)
Mites (Acari)	Baker (1956); Domrow (1979a,b, 1987, 1991, 1992); Gerozisis *et al*. (2008); Halliday (1998); Hughes (1976); Krantz (1978); Krantz and Walter (2009); Upton and Mantle (2010); Womersley (1934)
Ticks (Ixodida)	Arthur (1963); Barker and Walker (2014); Keirans and Litwak (1989), Roberts (1969, 1970); Russell *et al*. (2013); Service (1996); Smith (1973); Trapido *et al*. (1964), Upton and Mantle (2010)
Spiders (Araneida)	Brunet (1997); Clyne (1969); Davies (1986); Gerozisis *et al*. (2008); Lindsey (1998); Mascord (1970); Simon-Brunet (1994); Upton and Mantle (2010)
Cockroaches (Blattodea)	CSIRO (1991); Ebeling (1975); Gerozisis and Hadlington (1995); Gerozisis *et al*. (2008); Smith (1973)
Lice (Phthiraptera)	Ferris (1951); Goddard (1993, 2000, 2013); Mullen and Durden (2002); Russell *et al*. (2013); Service (2000); Smith (1973); von Kéler (1971)
True Bugs (Hemiptera)	CSIRO (1991); Doggett *et al*. (2003); Doggett (2013b); Gerozisis *et al*. (2008); Kettle (1995); Noack *et al*. (2011); Russell *et al*. (2013); Service (2000); Smith (1973); Upton (1991); Upton and Mantle (2010); Usinger (1966)
Fleas (Siphonaptera)	CSIRO (1991); Ebeling (1975); Gerozisis and Hadlington (1995); Gerozisis *et al*. (2008); Hopkins and Rothschild (1956, 1962, 1966, 1971); Kettle (1995); Mardon (1981); Russell *et al*. (2013); Service (1996); Smith (1973); Upton and Mantle (2010)
Mosquitoes (Diptera: Culicidae)	Anon (1985); Debenham *et al*. (1989); Dobrotworsky (1965); Lee *et al*. (1980, 1982, 1984, 1987a,b, 1988a,b,c, 1989a,b,c), Marks (1982); Russell (1993, 1996); Upton (1991); Upton and Mantle (2010)
Other biting Nematocera (Diptera)	Bellis *et al*. (2014); Colbo and Moorhouse (1979); Debenham (1978), Dyce *et al*. (2007); Lee (1963); Mackerras & Mackerras (1943, 1948a, 1948b, 1950); Marks (1982); Murphree and Mullen (1991); Smith (1973); Upton and Mantle (2010); Wharton (1948)
Non-biting Diptera	Cantrell (1981); Ferrar (1979); Francesconi and Lupi (2012); Greenberg and Singh (1995); McAlpine (1981); O'Flynn and Moorehouse (1980); Smith (1973, 1986); Spradbery (1991, 2002, 2017); Wallman (2001); Zumpt (1965)
Moths & Butterflies (Lepidoptera)	Common (1990); CSIRO (1991); Fisher (1985); Fracker (1914); Gerozisis *et al*. (2008); Peterson (1948); Southcott (1978); Stehr (1987); Stehr and Martinat (1987); Upton (1991); Upton and Mantle (2010)
Ants & Wasps (Hymenoptera)	Andersen (1991); CSIRO (1991); Gerozisis *et al*. (2008); Russell *et al*. (2013); Shattuck (1999); Upton (1991); Upton and Mantle (2010)
Delusionary parasitosis	Brenner *et al*. (1991); Darben *et al*. (1998); Ebeling (2002); Geary and Russell (2005); Goddard (1993, 2013); Hinkle (2010, 2011); Knight and Hausen (1994); Le and Gonski (2003); Long (1984); Potter (1997); Russell *et al*. (2013); Service (2000); Slaughter *et al*. (1998); Wykoff (1987)

plotted for both females and males, but population-adjusted data were not included to simplify the graphs. To account for variations in the number of specimens submitted per year, for the plot of total submissions by year (Figs 2a–10a), a correction was applied to the actual number of specimens for a particular class (e.g. tick and bird mite) based on the overall average number of specimens. The corrected data appear as a dashed line on the graphs. Submissions from female and male patients were statistically compared via the Microsoft Excel Chi Square function, and significance is noted in the figures.

RESULTS

Over the 30 years of 1988–2017, specimens from all the insect orders, as well as many Acarina, Araneae and other miscellaneous invertebrates, were submitted for identification. The arthropods included ants, bed bugs, bees, beetles, caterpillars (stinging and urticating), cockroaches, centipedes, fleas, flies (biting, synanthropic and myiasis), lice, mites (scabies, bird, rodent and stored product), scorpions, spiders, ticks, wasps and many other arthropods. These groups contain various medically important species that are known to suck blood, bite, sting, envenomate or cause skin reactions when in contact with a human host.

Overall, a total of 5655 samples were submitted, representing 25 orders, 188 families, 177 genera and 170 species. The most common species were *I. holocyclus* (708 specimens), *O. bursa* (506), *Cimex* spp. (149), *Clogmia* spp. (135), *P. capitis* (105), *P. pubis* (91) and *S. scabiei* (57). In addition, there were 235 samples submitted for scabies testing that proved negative and 1211 samples that were submitted for analysis that contained no evidence of any medically important arthropod.

The different life stages of ticks and mites were the most common arthropod specimens presented for identification. Dipteran specimens were numerous as well; most species were biting or non-biting midges, or common household fauna. The most frequent dipteran sample was the immature stage of moth flies from the Psychodidae family (as discussed below). Other dipteran species submitted were those involved in myiasis, in particular species within the Calliphoridae and occasionally Sarcophagidae. Contamination of a wound site or a cutaneous lesion by dipteran larvae was not uncommon but considered of little medical importance. The human bot fly *Dermatobia hominis* (Oestridae) was the most common exotic species of Diptera received. Samples containing the biting fly families Rhagionidae, Ceratopogonidae, Muscidae and Tabanidae, were also numerous.

Identification of Araneae was frequently requested (285 submissions), with the patient notes indicating that most specimens presented had bitten the patient, although only minor symptoms were indicated. The diversity of the Araneae submitted is indicated by the 29 families that were represented and 31 genera.

The most common genera included *Lampona* (37 specimens), *Misgolas* (32), *Eriophora* (24), *Isopeda* (21), *Atrax* (19), *Lycosa* (18) and *Badumna* (16). The majority of the spiders were sent from private pathology practices. Some of the more dangerous species were collected from homes, pools and gardens and often badly damaged when received for identification preventing species identification.

The hemipteran specimens were dominated by bed bugs (Cimicidae: *Cimex*). Other medically important species submitted were from the families Pentatomidae, Lygaeidae and Reduviidae. Additionally, 30 specimens of Thaumastocoridae were also received.

Regarding Hymenoptera, the honey bee *Apis mellifera* (17 specimens) was the most common species submitted, with often only the aculeus (sting) collected. Ants and wasps were occasionally submitted, particularly the vespid wasps *Vespula* (22) and *Polistes* (9). These were of particular interest due to their medical significance, being capable of inflicting painful stings and, in some cases, anaphylaxis.

From the Siphonaptera, the cat flea *Ctenocephalides felis* was the most commonly submitted, with 39 specimens. In recent years, there has been a decline in the submission of this species. The other flea of note was the exotic Chigoe flea *Tunga penetrans* (14), brought into Australia by travellers.

The majority of Coleoptera specimens were household species usually associated with stored food products or various species of dermestid beetle. The highly bristled larval stages of dermestid beetles are well known for their association with contact dermatitis, with *Anthrenus* (22 specimens) being the most commonly submitted genus, followed by *Anthrenocerus* (12). Additionally, there were several samples of medically important species within the families of Meloidae and Staphylinidae, notably the blister beetles.

Lepidopteran specimens were routinely received, and most species were from the medically important family of Lymantriidae (15 specimens). Other medically important families (e.g. Anthelidae and Limacodidae) were submitted, albeit in small numbers (<5). Pyralidae (31) was well represented, as this family contains several species of well-known pantry pests that infest stored products. The immature stages were far greater in number than the adult moths. Often, the immature stage had been regurgitated by patients and hence the reason for being sent to our laboratory for identification.

Cockroaches (Blattodea: 37 specimens) contain a number of species that can inhabit domestic dwellings and as a consequence can be found in many unwanted locations. The smaller nymphal stages of some common species were occasionally identified from situations that required medical intervention (e.g. removal

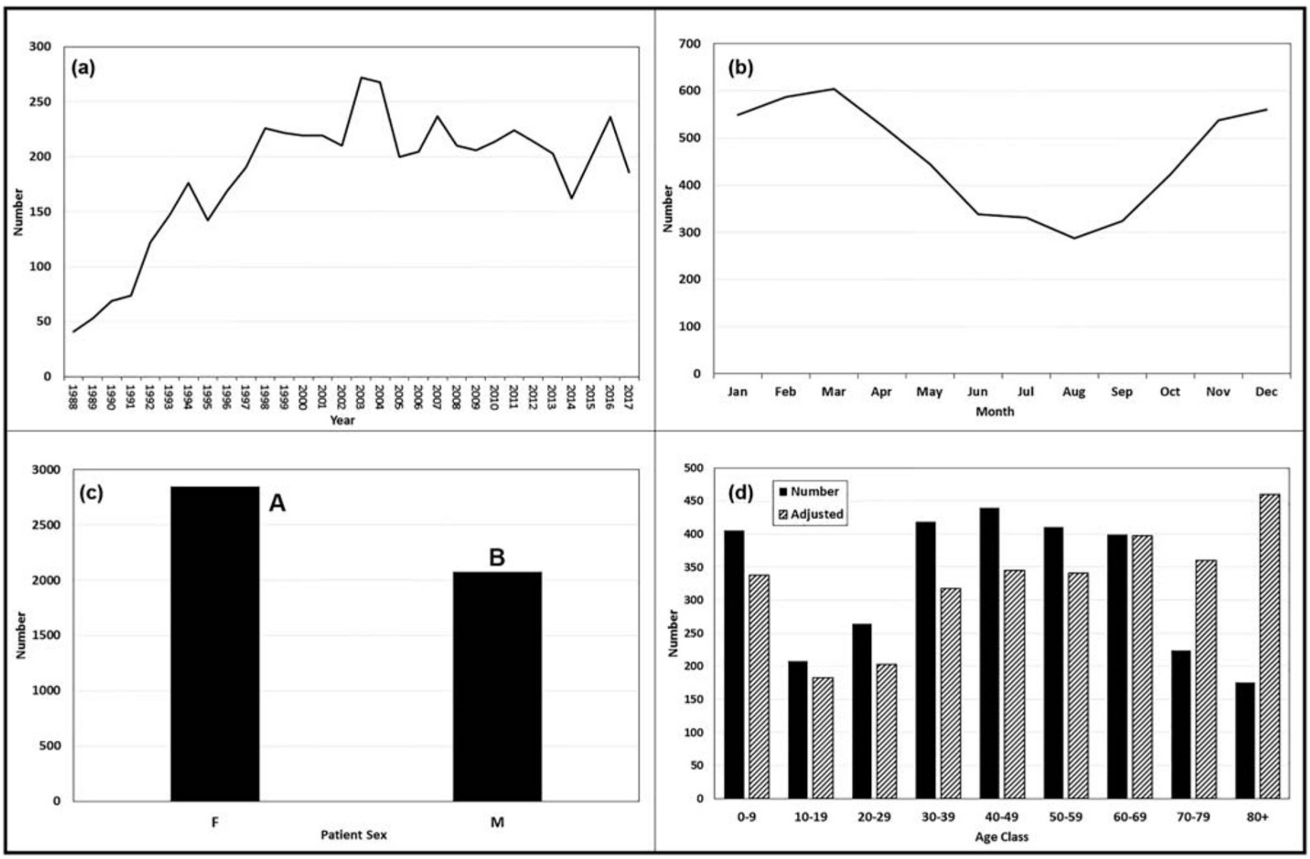

Fig. 1. Trends of overall specimens sent to the Department of Medical Entomology for identification, 1988–2017. (a) Submissions by year. (b) Submissions by month. (c) Submissions by female (F) vs. male (M) patients. Note that the letter next to the bar graph denotes the statistical relationship; different letters indicate a statistical difference. (d) Patient age classes; number = actual number of specimens, adjusted = adjusted for population numbers of the particular age class. The *Y*-axis is the same for actual and age adjusted numbers.

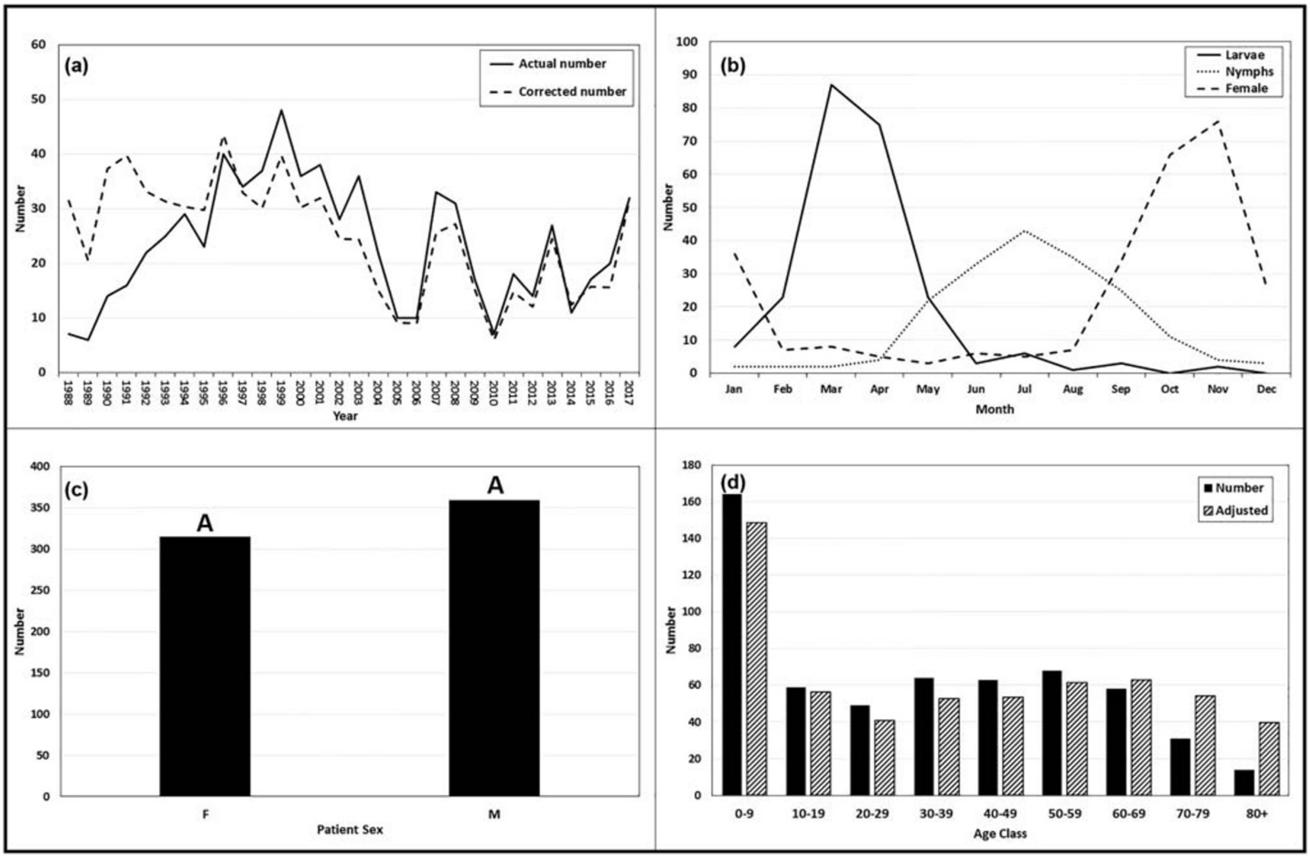

Fig. 2. Trends of the Australian paralysis tick (*Ixodes holocyclus*) specimens sent to the Department of Medical Entomology for identification, 1988–2017. (a) Submissions by year; solid lines represents actual number, dashed line represents corrected number (see text). (b) Submissions by month; solid line represents larval ticks, dotted line represents nymphal ticks, and dashed line represents adult female ticks. (c) Submissions by female (F) vs. male (M) patients. Note that the letter next to the bar graph denotes the statistical relationship; the same letters indicate no statistical difference. (d) Patient age classes; number = actual number of specimens, adjusted = adjusted for population numbers of the particular age class. The *Y*-axis is the same for actual and age adjusted numbers.

from a patient's ear). Various species of cockroaches were submitted in relation to the contamination of food products or sent on the suspicion that they were a bed bug.

Species of Psocoptera were frequently sent (70 submissions) and labelled as the causative agent of a multitude of medical conditions. Thrips (Thysanoptera) were submitted on 30 occasions. Species of Collembola (16) were another arthropod that was collected, suspected as the cause of people's malaise. Small numbers of Thysanura and Dermaptera were submitted (10 in total); however, what was significant was that on three occasions, they were retrieved from the ear canal.

Figure 1 contains the graphs associated with all the specimens. Over the years 1988–2003, there was an annual rise in specimens submitted to the laboratory, but these plateaued thereafter (Fig. 1a). Fewer specimens were submitted during the winter months (Fig. 1b), and, statistically, female patients submitted more specimens than male (Fig. 1c). Regarding age class of patients, many were less than 10 years, with a peak with the middle ages of 30–70 years, although the adjusted data showed that patients over 80 submitted more specimens based on population size (Fig. 1d).

Figure 2 presents graphs for *I. holocyclus*. Over the 30 years, there appeared to be no solid trend in submissions (Fig. 2a); however, seasonally, strong trends were clearly evident (Fig. 2b). Larval ticks peaked in autumn, nymphs during winter and adult ticks during spring. There was no statistical difference in the submissions by sex of patient (Fig. 2c). Patients from the age class of 0–9 predominated and were more than twice as frequent as any other age class, even with the population-adjusted data (Fig. 2d).

Figure 3 includes the various plots for *O. bursa*. Submissions peaked during 2000 and have gradually declined since (Fig. 3a). Seasonal trends are evident, with a peak in activity over November to March, with few specimens submitted during winter (Fig. 3b). Female patients were statistically more represented than males (Fig. 3c). Young to middle-age adults submitted the majority of the *O. bursa* specimens (Fig. 3d).

The trends associated with *Cimex* spp. are depicted in Figure 4. There was a dramatic spike in submissions in 2004, which was associated with the start of the global resurgence (Fig. 4a). Seasonally, *Cimex* spp. were less evident during the winter months (Fig. 4b). Female and male patients were not statistically different (Fig. 4c); however, there was a strong age association with adults in the 30–49 age classes more frequently submitting *Cimex* spp. (Fig. 4d).

The graphs associated with *Clogmia* spp. are presented in Figure 5. For this genus, it was the larval stage that was submitted, and the clinical notes stated that most were collected from a toilet or from faeces or urine. Over the years, specimens from this group have gradually increased (Fig. 5a). There was a moderate seasonal trend with slightly fewer samples submitted during the winter months (Fig. 5b). Female vs. male patients were not statistically different (Fig. 5c), and young to middle-age adults submitted the majority of the samples (Fig. 5d).

For *P. capitis*, there was a peak in submissions at the start of the new millennium and again in 2011 (Fig. 6a). Seasonally, there was a slight drop in numbers during the winter months with peak submissions during late summer and early autumn (Fig. 6b). There was a very strong and significant relationship in the sex of the patients, with the number of female patients almost three times that of males (Fig. 6c). The youngest (0–9 years) dominated the age class of patients, although the population-adjusted data show another peak in the over 80 age group (Fig. 6d).

Pthirus pubis showed little in the way of trends over the 30 years (Fig. 7a), although seasonally, there was a slight peak in submissions during autumn (Fig. 7b). Males were significantly more associated with *P. pubis* infestations than females (Fig. 7c), and adults in the sexually active years were more associated with specimens (Fig. 7d). Clinical notes indicated the samples of the pubic louse were removed from the pubic and perianal areas, and occasionally from other areas of body hair. Younger patients (<10 years of age) presenting with this infestation were found to have infested eyelash and/or eyebrow areas in the absence of coarser body hair.

Figure 8 depicts the trends with *S. scabiei*. Over the 30 years under study, submissions have not changed notably (Fig. 8a). Seasonally, there is a strong association with the winter months (Fig. 8b). There was no statistical difference between the sex of the patients (Fig. 8c), although older age classes (>70 years) were more considerably representative of the patients submitting samples (Fig. 8d).

Interestingly, only around one fifth of the samples submitted for scabies analysis produced a positive *S. scabiei* result, and the negative samples are plotted in Figure 9. In the years since 2011, there has been a general increase in negative *S. scabiei* samples (Fig. 9a). Unlike in the positive samples, there is no seasonal trend with the negative samples (Fig. 9b). Again, female and male patients are equally likely to be represented with no statistical difference (Fig. 9c). The age trend in the negative samples compared with the positive samples was not dissimilar (Fig. 9d).

One form of sample that has increased over the last 30 years has been those with no evidence of any medically important arthropod (Fig. 10a). While there appears to be little seasonal trend with these samples (Fig. 10b), there is a strong and significant association with female patients (Fig. 10c), especially in the 40–69 age classes (Fig. 10d). The majority of these collections comprised insect fauna common to domestic household environments, but of no medical significance, or the collection contained only non-entomological material.

Table S1 in the Supporting Information lists the source of the specimens, when stated on the request forms. Almost one third (32.8%) stated that the patient was either stung or bitten, with a slightly lower percentage (26.3%) just noting that the sample was on the body, without any specific detail. Close to one fifth (17.1%) were submitted for identification purposes, with no details of any clinical association, and 13% were collected from the patient's home. These four locations constituted almost 90% of the specimens. The other locations show the diversity of situations where medically important arthropods can be encountered.

Medically important arthropods brought into Australia by patients through overseas travel are depicted in Table 3. A number of these included myiasis flies such as *D. hominis*, which was the most common of all myiasis species with 28 specimens, the Tumbu fly *Cordylobia anthropophaga* (14 specimens) and Lund's fly *Cordylobia rodhaini* (3). The other myiasis species was *T. penetrans*, with 14 presentations of the adult female flea. Ticks also featured prominently amongst the exotics, with a range of species recorded. Some exotic specimens brought into the country and sent for identification, which are now endemic to Australia, included the tropical bed bug *Cimex hemipterus* and the brown dog tick *Rhipicephalus sanguineus*. What is evident is that most of these exotic pests are body parasites that remain attached to the body for some days, allowing for the transport of the arthropod around the world.

New records for Australia over the 30 years of the program are documented in Table 4. Most are species new to Australia, although in the case of the platypus tick *Ixodes ornithorhynchi*, which is a local species, this is the first documented case of the tick biting a human. Two new species recorded for the first time during this 30 year period have now become established, namely, brown-legged mite *Aleuroglyphus ovatus* and *C. hemipterus*.

Unusual case studies for particular arthropod groups are presented in the Supporting Information. A number of images to aid the taxonomic identification of diagnostically challenging specimens are also presented in the Supporting Information.

DISCUSSION

General trends

The large number of specimens received over 1988–2017 provides an insight into the range, the frequency, the time of the year and the diversity of the medically important arthropods that impinge on the community of Australia. Over the 30 years, all of the medically important arthropods have been well represented. Interestingly, however, while mosquitoes are probably the most common arthropod that bites humans in Australia, very few have been submitted to the identification service. For the most part, the transitory blood feeders that feed outside the home (such as mosquitoes and midges) have been poorly represented. This is in contrast to the transitory feeders within the home (e.g. bed bugs and bird mites), which were very commonly submitted. Presumably mosquitoes are better known by the public than most of the other insects and thus less likely to be submitted

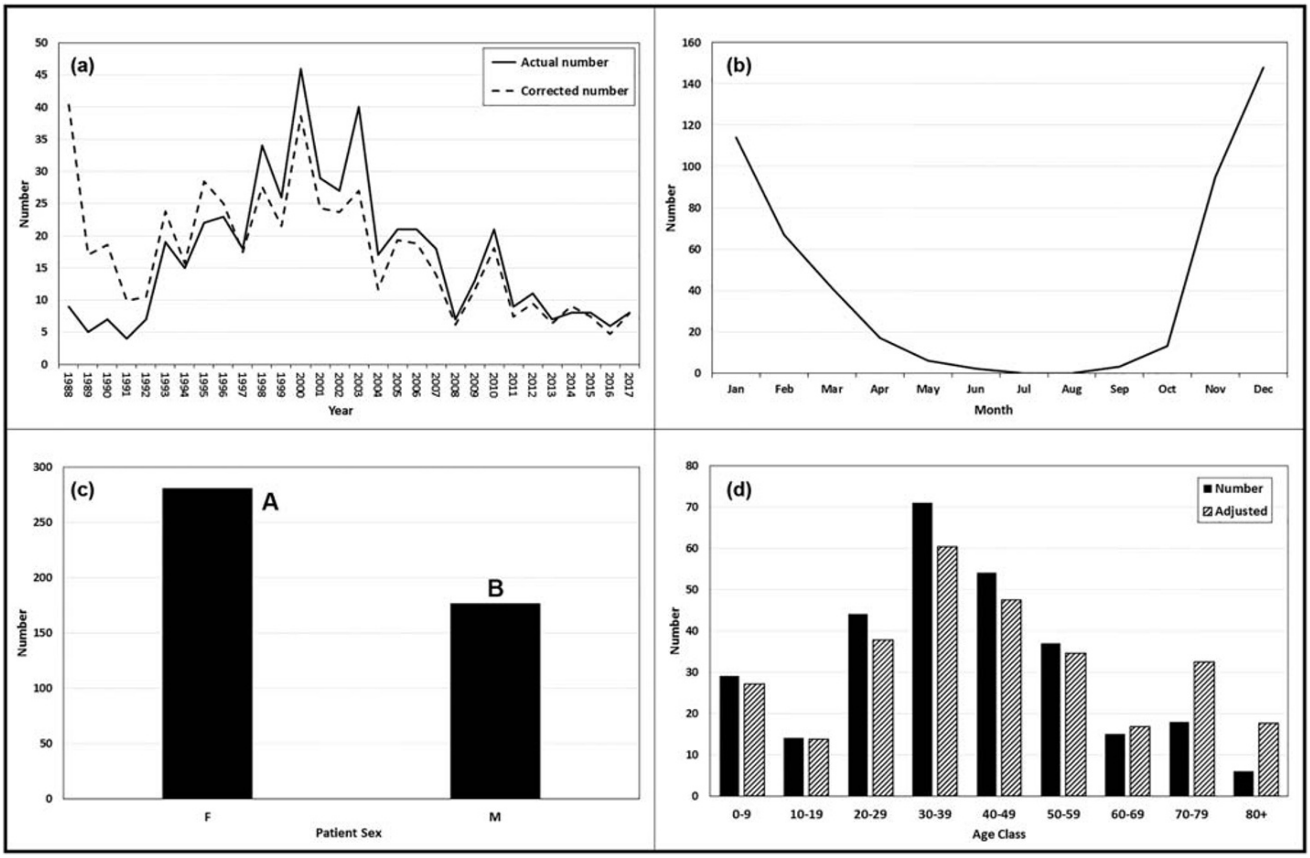

Fig. 3. Trends of bird mite (*Ornithonyssus bursa*) specimens sent to the Department of Medical Entomology for identification, 1988–2017. (a) Submissions by year; solid line represents actual number, and dashed line represents corrected number (see text). (b) Submissions by month. (c) Submissions by female (F) vs. male (M) patients. Note that the letter next to the bar graph denotes the statistical relationship; different letters indicate a statistical difference. (d) Patient age classes; number = actual number of specimens, adjusted = adjusted for population numbers of the particular age class. The *Y*-axis is the same for actual and age adjusted numbers.

for identification, plus transitory feeders are less likely to be noticed as they are so quick to imbibe a blood meal. Generally, it was the arthropod parasites that stayed on the human body for an extended period that were more likely sent to the identification service. This included the ticks, head and pubic lice, and scabies. This is backed up by the fact that over one quarter of the specimens were taken from the body of the patient (Table S3). The species of mosquito that was most commonly submitted was *Toxorhynchites speciosus* (15 samples). Many people email images of this species to our Department, as the mosquito is a very large species (the biggest of all mosquitoes) and there is the concern it may be an exotic. However, it is a common endemic mosquito in regions where it naturally occurs, does not bite and is of no medical importance.

The lack of specimens of the transitory blood feeders outside the home is but one limitation of the data set in the examination of which arthropods of medical importance attack humans in Australia. For example, it is very difficult to establish trends over the 30 year period based on annual submissions. From when the service first became established in 1987, the annual number of specimens submitted to the service rose steadily up to the early years of the new millennium, but subsequently stabilised, with around 200 annually (Fig. 1a). Over the years, many specimens have been sent via private pathology laboratories; and when certain arthropods were repeatedly identified, the laboratories stopped sending these, preferring to undertake the identification themselves. Currently, no private pathology group in Australia has any expertise in medical entomology and misidentifications do occur. We have also found that the pest control industry routinely misidentifies arthropods. This often results in unnecessary applications of pesticides and expense to the client, and enormous stress without resolving the issue. The fundamental basis of all pest control should be the accurate identification of the pest before any treatment is undertaken.

The submissions per month are averaged over the 30 year interval, and presumably, this provides a good representation of trends, and several are evident as discussed in detail with the main arthropods collected. The overall reduced number of submissions during the winter months is not unexpected, as arthropods are less active or even absent in the cooler weather and people spend less time undertaking outdoor activities (Fig. 1b).

Figure 1c shows that females have statistically submitted more specimens compared to males. However, this relationship needs to be interpreted with a degree of caution. Women are more likely to consult a medical practitioner than men. An indication of this is that across Australia, during the financial year of 2017–2018, women made almost 240 million Medicare claims compared to the 174 million of men (Australian Government

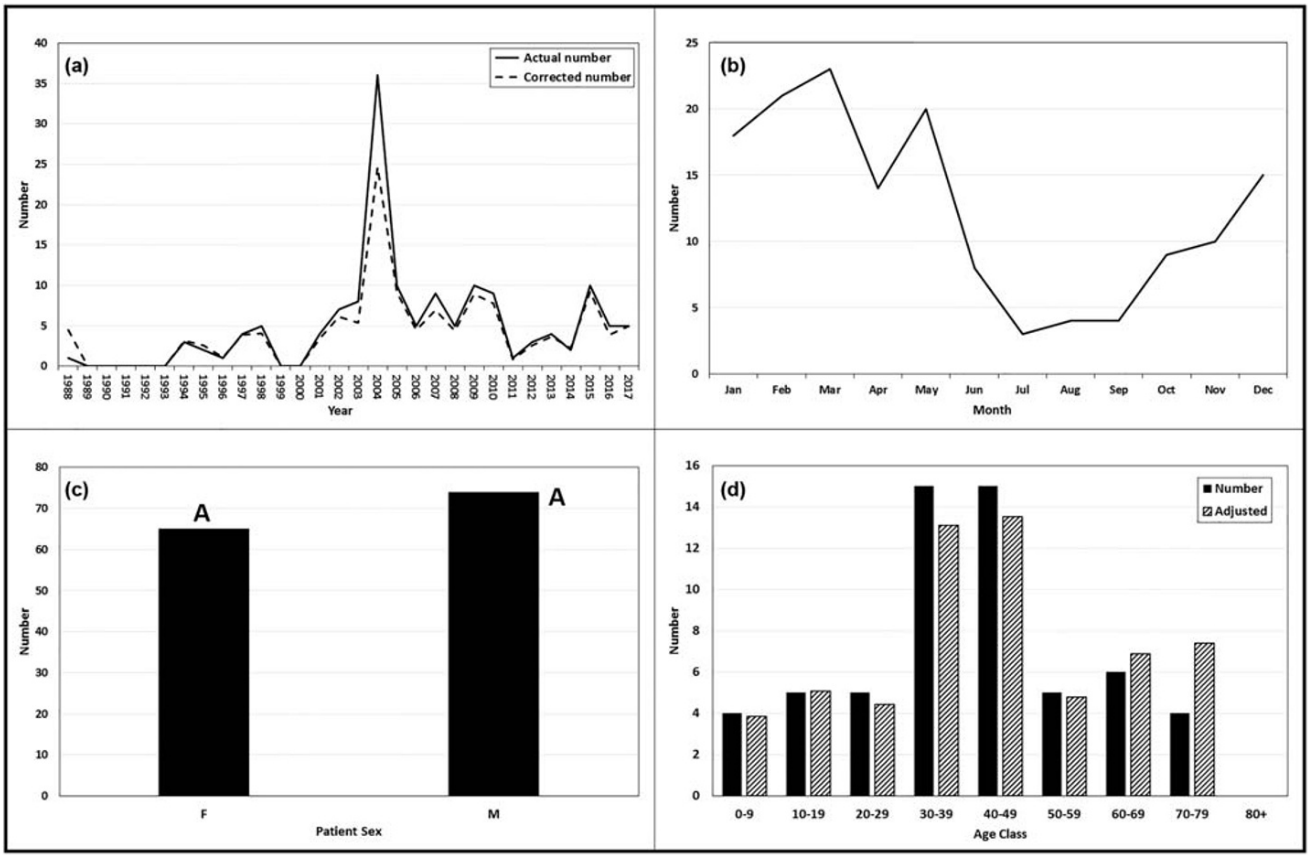

Fig. 4. Trends of bed bug (*Cimex* spp.) specimens sent to the Department of Medical Entomology for identification, 1988–2017. (a) Submissions by year; solid line represents actual number, and dashed line represents corrected number (see text). (b) Submissions by month. (c) Submissions by female (F) vs. male (M) patients. Note that the letter next to the bar graph denotes the statistical relationship; the same letters indicate no statistical difference. (d) Patient age classes; number = actual number of specimens, adjusted = adjusted for population numbers of the particular age class. The *Y*-axis is the same for actual and age adjusted numbers.

Department of Health 2018), and this trend has not changed substantially for decades. Thus, women will visit a medical practitioner on roughly 30% more occasions than men. Conclusions are difficult to draw, as these social differences between the sexes cannot be readily adjusted for in the data. It also means that when more specimens are submitted by men, even if not statistically different, some trend may be evident, which is confounded by the fact that men are less often likely to consult a medical practitioner.

Regarding the different age classes for all the specimens compared, for the most part, a normal distribution is indicated with a peak seen in middle-aged adults for all samples submitted (Fig. 1d). However, there were many specimens from children under 10 years of age. Perhaps younger children are less likely to notice a parasite infestation and subsequently attempt to eliminate it, which appears to be the case for head lice. Ticks were also associated with this age class, and from anecdotal experience (Doggett, unpublished data), children are less likely to notice an attached tick and not likely to remove it until the tick has been present for some days. The population age-adjusted data show a slightly different trend, with the age group of over 80 as submitting the most specimens. There was an increasing trend of submissions with age groups over 10 with the age-adjusted data.

Beyond the lack of details as to where the specimens may have been acquired, the samples themselves can be problematic. Private pathology departments who receive a ‘foreign body’ for identification from human skin often stain and section the specimen for identification (see example with ticks below and Figure S1 in the Supporting Information). The resulting specimen can be difficult, if not impossible, to identify to species level, as this form of preparation method damages or severely restricts taxonomic details necessary for identification. Some arthropods attached to a patient have been forcibly removed, destroying the specimen in the process. The challenge is then to assess key diagnostic features. For scabies samples, it is not uncommon that a very small skin scraping is submitted for pathological analysis. In this case, the sample will be examined but may prove inadequate, and the report will record this as ‘insufficient sample’. Samples have often been sent in water, rather than a preservative, and is unable to be processed by the time it reaches the laboratory. Images of ‘bugs’ found on patients are often the preferred method of sending specimens by some medical practitioners. Typically, many photographs are out of focus and captured using technology (e.g. mobile phone) lacking both the resolution and magnifying capability to reveal salient taxonomic features.

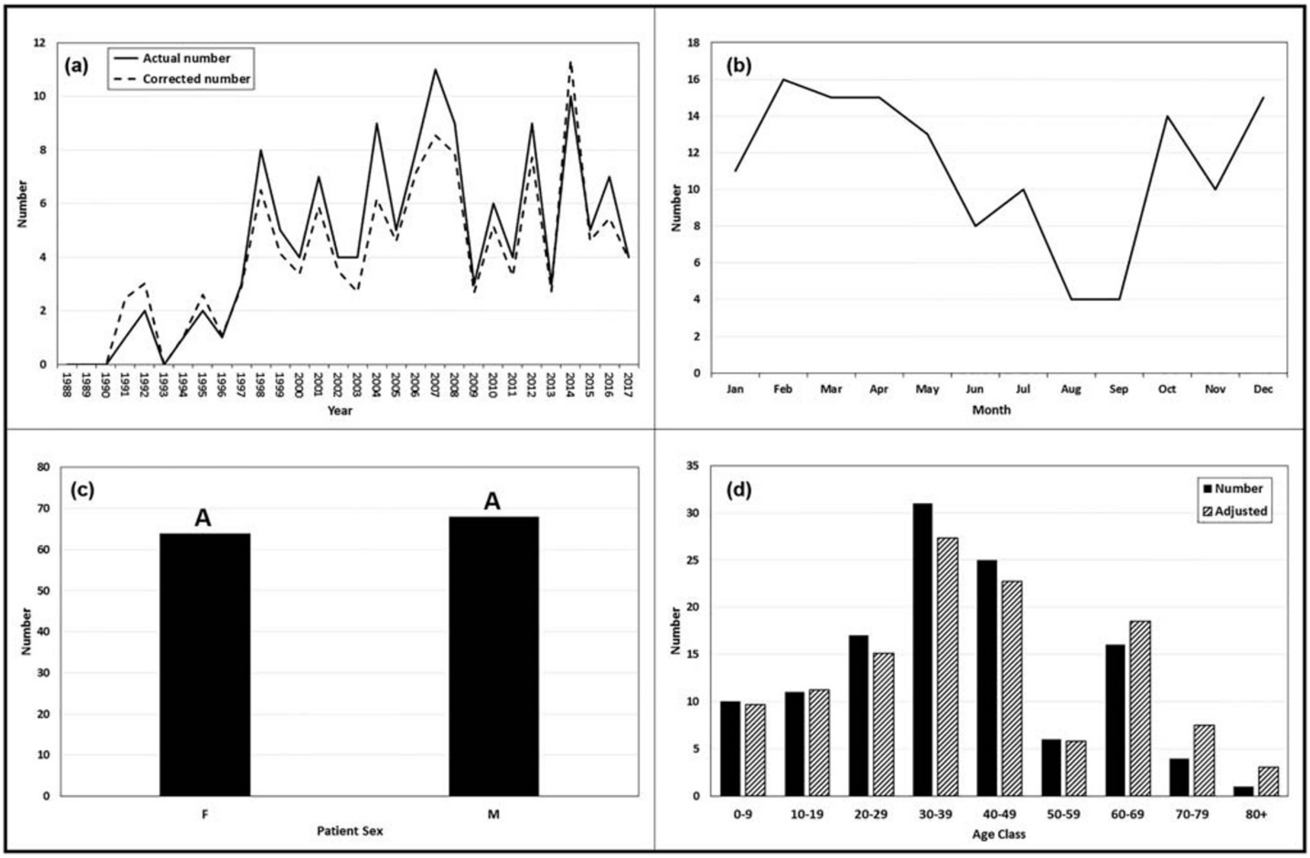

Fig. 5. Trends of moth fly (*Clogmia* spp.) specimens sent to the Department of Medical Entomology for identification, 1988–2017. (a) Submissions by year; solid line represents actual number, and dashed line represents corrected number (see text). (b) Submissions by month. (c) Submissions by female (F) vs. male (M) patients. Note that the letter next to the bar graph denotes the statistical relationship; the same letters indicate no statistical difference. (d) Patient age classes; number = actual number of specimens, adjusted = adjusted for population numbers of the particular age class. The *Y*-axis is the same for actual and age adjusted numbers.

The ticks

Ixodes holocyclus was the most common species received during the 30 year analysis period. Little can be stated about the trends in annual submissions (Fig. 2a), as they have fluctuated over the years. However, a strong seasonality was observed with the different stages, with larvae being the predominant stage in the autumn, nymphs in winter and adults in spring (Fig. 2b). This is in line with previously published observations of the species on companion animals (Baxter *et al*. 2009; Eppleston *et al*. 2013). The sex of the patients was not a statistically different feature (Fig. 2c); however, there were more male patients, which may be significant in light of the discussion above. Further work is required to elucidate risk factors to tick exposure before any definitive conclusions can be made. Another result that was evident was the large number of children under 10 years of age from which *I. holocyclus* specimens were submitted (Fig. 2d). This age class more than doubled that of the next most frequent, even when adjusted for population age data. This observation is in accord with past reports, e.g. of the 20 documented deaths due to tick paralysis, 70% were in children under 4 years of age (Doggett 2004). In some cases, the tick was attached to children in unusual locations on the body, such as on the conjunctiva of the eye (Teong *et al*. 2015). Most of the time, however, the clinical notes provided no details on where on the body the tick was attached.

Ticks, in particular *I. holocyclus*, have been very heavily discussed in the media over recent years; thus, it is surprising that submissions for identification have not increased over time. Firstly, there has been the Lyme disease controversy, with a number in the medical community suggesting the condition was present in Australia. This was in spite of intensive investigations during the early 1990's that failed to detect any evidence of the causative agent, *Borrelia burgdorferi* s.l. (Russell *et al*. 1994), and that vector competence experiments demonstrated *I. holocyclus* was refractory, i.e. unable to transmit the bacteria (Piesman & Stone 1991). Furthermore, there is no scientific evidence to demonstrate that Lyme disease occurs in Australia (Chalada *et al*. 2016; Collignon *et al*. 2016; Irwin *et al*. 2017). Secondly, there was the discovery of syndrome known as mammalian meat allergy, which can develop following the bite of *I. holocyclus*, as discussed in the Introduction (van Nunen 2015, 2019; van Nunen *et al*. 2009). These two issues alone have led to a renewed interest in tick research within Australia. This has included the search for pathogens, and a range of new organisms

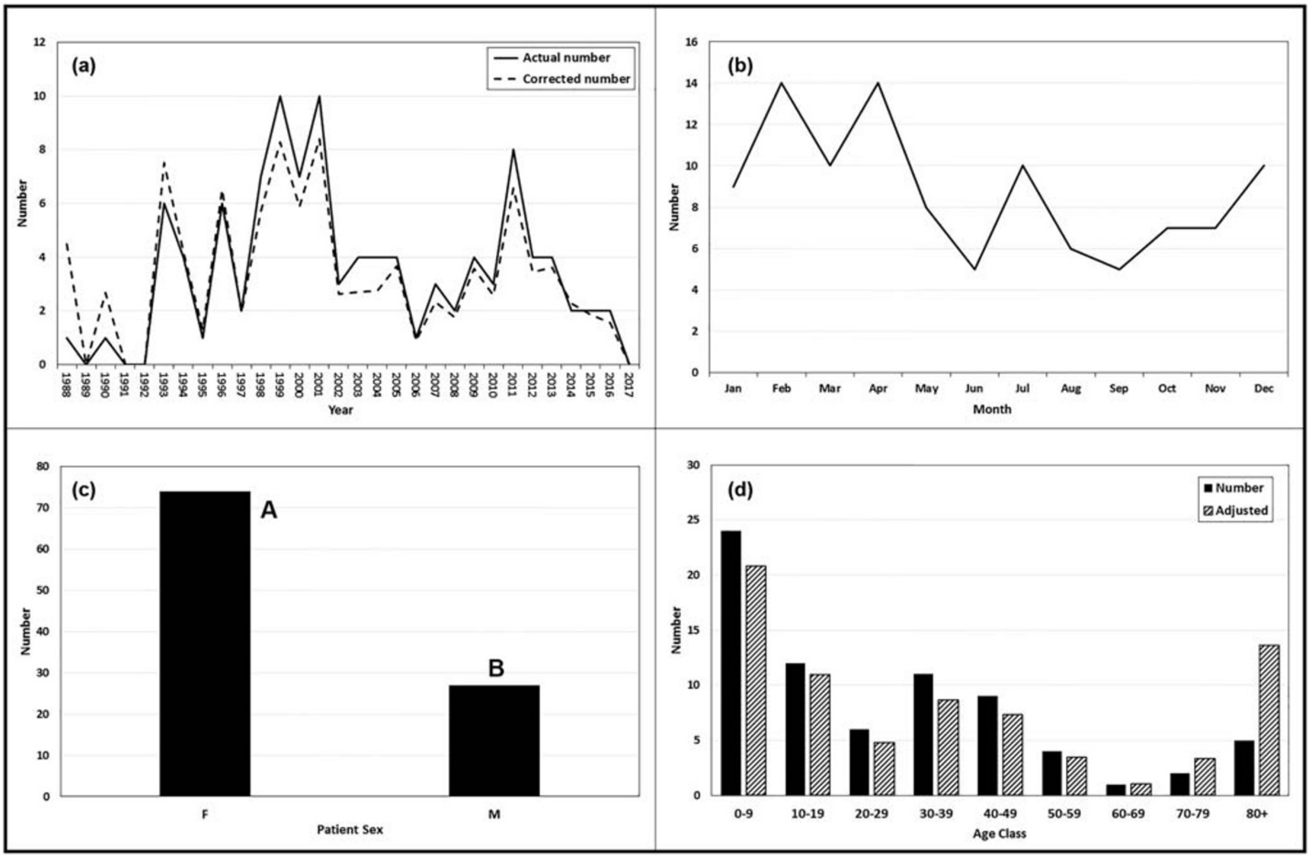

Fig. 6. Trends of head lice (*Pediculus capitis*) specimens sent to the Department of Medical Entomology for identification, 1988–2017. (a) Submissions by year; solid line represents actual number, and dashed line represents corrected number (see text). (b) Submissions by month. (c) Submissions by female (F) vs. male (M) patients. Note that the letter next to the bar graph denotes the statistical relationship; different letters indicate a statistical difference. (d) Patient age classes; number = actual number of specimens, adjusted = adjusted for population numbers of the particular age class. The *Y*-axis is the same for actual and age adjusted numbers.

have been identified from *I. holocyclus*, including one that closely aligns with a known human rickettsia from overseas (Gofton *et al*. 2015, 2016; Harvey *et al*. 2019; O'Brien *et al*. 2018). Recent research has shown that killing attached *I. holocyclus* ticks *in situ* prior to removal reduces the risk of adverse clinical sequelae (Taylor *et al*. 2019), and the first investigations on *I. holocyclus* bite avoidance through the use of repellents and impregnated fabrics have now been undertaken (Panthawong *et al*. 2020a, 2020b; Sukkanon *et al*. 2019).

Overall, ticks represented the largest group of arthropods submitted with some 821 specimens. As noted, *I. holocyclus* constituted the vast majority, and a number of *Ixodes* (16) could not be identified morphologically beyond the genus level, as they were so badly damaged when removed from the patient, although they were most likely *I. holocyclus*. In several instances, the ticks were sectioned. The arthropod was removed from the patient as a suspect lesion (rather than as a putative arthropod) and sent to an anatomical pathologist for cytological analysis. A sectioned tick is very hard to identify, although legs, chitin (with the associated cuticular surface pattern) and other structures may be noted along with the size (see Fig. S1).

The kangaroo tick *Amblyomma triguttatum* was the next most common species with 23 submissions. These were all collected from dryer regions of the country, notably from inland NSW, west of the Great Dividing Range. *Ambylomma triguttatum* is an aggressive biter of humans and has been reported causing local skin reactions after removal, suggesting a delayed hypersensitivity reaction (Pearce & Grove 1987). While the species is not known to transmit pathogens to humans, a novel rickettsia was recently detected from this tick on Barrow Island in Western Australia after reports of a possible rickettsial infection in local workers (Abdab *et al*. 2017).

For other species of ticks, *Ixodes tasmani* (11 submissions) and *R. sanguineus* (11) were the next most common. The *I. tasmani* were all collected from patients in coastal regions of NSW where the species is sympatric with *I. holocyclus*. The majority of *R. sanguineus* were collected from dogs, with only two reports of the species biting humans. In one case, a specimen of *R. sanguineus* was found in imported goods from Indonesia (Table 4). Other tick species that were collected from humans included *Haemaphysalis longicornis* (7 specimens), *Haemaphysalis bancrofti* (6), *Amblyomma moreliae* (5), *Ixodes australiensis* (1) and *I. ornithorhynchi* (1). The *I. australiensis* was removed from a female patient in Margaret River, WA, in 2006, and this predates a recent publication that suggested the earliest record of this tick attacking humans occurred in 2017 (Kwak 2018). The *I. ornithorhynchi* is a new record for biting humans. The female patient was from northern Victoria and is

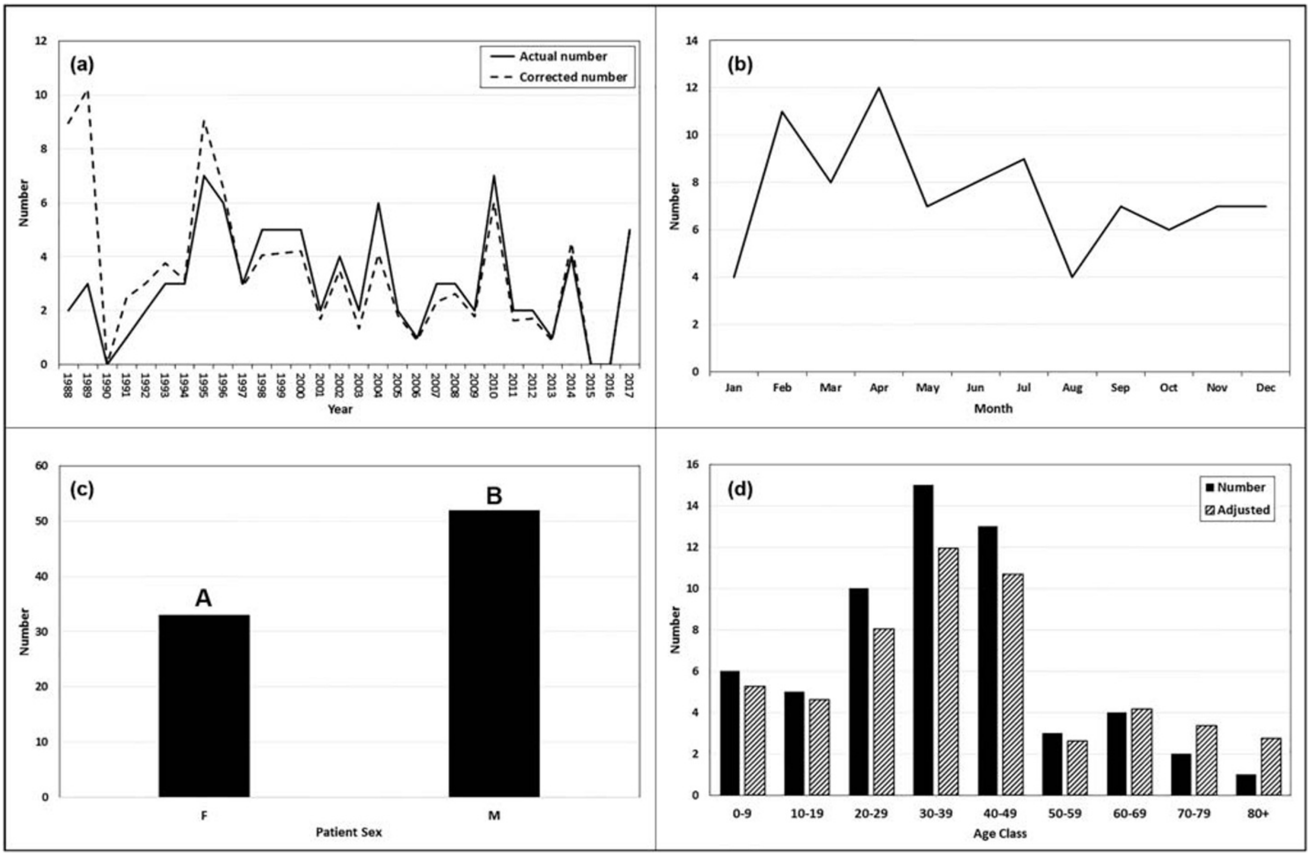

Fig. 7. Trends of pubic lice (*Pthirus pubis*) specimens sent to the Department of Medical Entomology for identification, 1988–2017. (a) Submissions by year; solid line represents actual number, and dashed line represents corrected number (see text). (b) Submissions by month. (c) Submissions by female (F) vs. male (M) patients. Note that the letter next to the bar graph denotes the statistical relationship; different letters indicate a statistical difference. (d) Patient age classes; number = actual number of specimens, adjusted = adjusted for population numbers of the particular age class. The *Y*-axis is the same for actual and age adjusted numbers.

an animal carer who handles platypus, the main host for the tick. Some ticks were also collected from residences in association with bird nests such as *Argas lagenoplastis* (2 specimens) and *Ornithodorus macmillani* (2).

One tick species that was poorly represented was *Ixodes cornuatus*. This is a species reported by Roberts (1970) as occurring in 'southern coastal New South Wales', Victoria and Tasmania. However, only two samples were sent in the 30 years: one from Wee Jasper near the Australian Capital Territory and the other from New Norfolk in Tasmania. Of the *I. holocyclus* submitted, 98.3% were from NSW, with many from the south coast of NSW and a small number (10) from Victoria. Yet not one specimen from these regions was *I. cornuatus*. Furthermore, our investigations into Lyme disease during the early 1990's resulted in 7352 *I. holocyclus* being collected from NSW, also with no *I. cornuatus* (Russell *et al*. 1994). It appears that most of the reports of this species in NSW, and probably Victoria, may have been misidentifications, and quite possibly *I. holocyclus* and *I. cornuatus* occupy very different ecological niches in these regions.

The two species are normally distinguished by the length of the cornua on the head (Roberts 1970), with this structure being longer in *I. cornuatus*; however, we have found this to be an unreliable characteristic, and the cornua can be quite well defined even in *I. holocyclus*. Jackson *et al*. (2002) attempted to more accurately describe the two species and came to the conclusion that the males of *I. holocyclus* and *I. cornuatus* are 'virtually identical'. For the females of the species, the authors stated that 'no individual parameter allowed the identification' of the two species. More recently, Barker *et al*. (2014) reported on the difference in the colouration of the legs between the species, in that the front and hind legs of *I. holocyclus* are darker than the middle pair, whereas *I. cornuatus* has a uniform colouration of all legs. As neither group of authors included photographs of live specimens of both species, the adults of both species are included in the Supporting Information (Figs S2 and S3). When the two species are juxtaposed, gross morphological differences are clearly evident, even in the included images. The legs are differently coloured as noted by Barker and colleagues, and body colouration is also markedly different, with *I. cornuatus* being deeper red in both adult stages (we have also observed this with the nymphs and larvae). The latter species is also larger, around 1 mm longer in both adult stages. It can only be assumed that as Jackson and colleagues did not note these morphological differences, they in fact failed to collect any *I. cornuatus* and probably worked on a sub population of *I. holocyclus*.

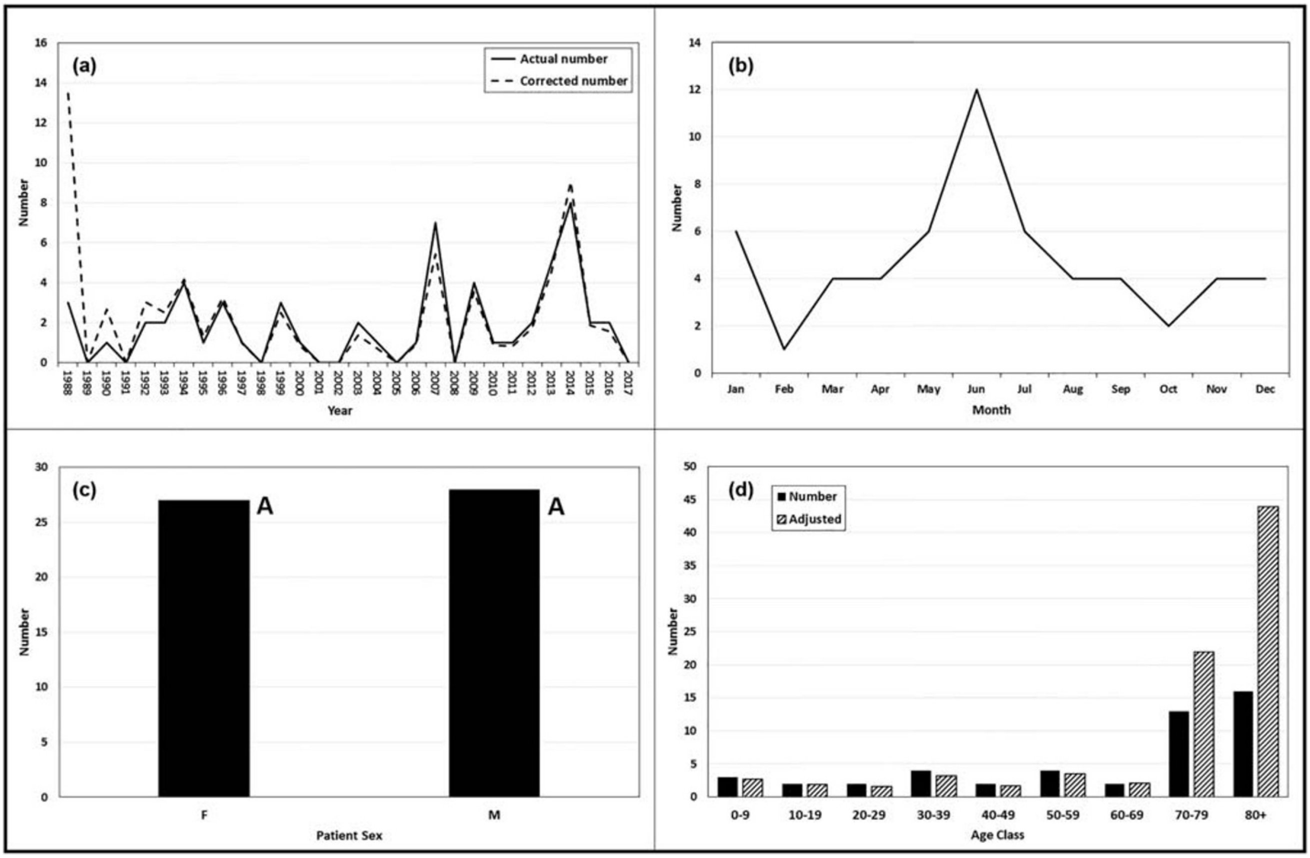

Fig. 8. Trends of scabies (*Sarcoptes scabiei*) specimens sent to the Department of Medical Entomology for identification, 1988–2017. (a) Submissions by year; solid line represents actual number, and dashed line represents corrected number (see text). (b) Submissions by month. (c) Submissions by female (F) vs. male (M) patients. Note that the letter next to the bar graph denotes the statistical relationship; the same letters indicate no statistical difference. (d) Patient age classes; number = actual number of specimens, adjusted = adjusted for population numbers of the particular age class. The *Y*-axis is the same for actual and age adjusted numbers.

It is important to accurately distinguish the two species and their distribution, as the information has implications for human health and tick-borne disease prevention. *I. cornuatus* has been reported as causing paralysis in a child (Tibballs & Cooper 1986); however, it is likely the tick was acquired in southern Qld and was probably a misidentification on the basis of the lack of evidence that the species occurs in this region and from the data discussed above. The other reports of paralysis associated with *I. cornuatus* have been with dogs. In the report of two cases of tick paralysis in dogs from Victoria, Beveridge and colleagues (Beveridge *et al*. 2004) stated that identification of the tick was based on the description in the Jackson *et al*. (2002) paper, and thus there must also be doubts about the identity of these ticks for the reasons outlined above. Mason *et al*. (1974) reported on cases of tick paralysis in animals from Tasmania; however, we have received a specimen of *I. holocyclus* from Tasmania that showed the distinctive characteristics of the species as outlined above. This again casts aspersions on the idea that *I. cornuatus* causes paralysis. Barker *et al*. (2014) proposed that *I. cornuatus* should be given the common name 'southern paralysis tick'; however, in light of the questions about the tick causing paralysis, this name should not be used until this species is unambiguously linked with paralysis. In the meantime, a more appropriate common name would be the 'southern brown *Ixodes*' in light of its colouration.

Bird mites

Bird mites (also called the 'tropical fowl mite') *O. bursa*, constituted the second largest group with some 506 submissions. Again, few conclusions can be made in terms of samples by year (Fig. 3a), with a peak in 2000 and a gradual decline in submissions thereafter. This is likely to have been artificial for the reasons discussed above. However, the seasonal trend is very distinct, with a sharp drop during the winter months and a large peak during the spring to summer period (Fig. 3b). *Ornithonyssus bursa* are associated with exotic birds that typically nest in the roof cavity of homes (Doggett & Geary 2003; Geary & Doggett 2016; Nagaratnam *et al*. 2019), although some patients may acquire bites from this species after collecting eggs and/or handling infested fowl (Doggett & Geary 2003). In spite of misinformation in journals about this species (e.g. Watson 2003), such as invading the body, the mite tends to only 'test-bite' humans and not invade the skin (Doggett & Geary 2003). The test-biting can give the

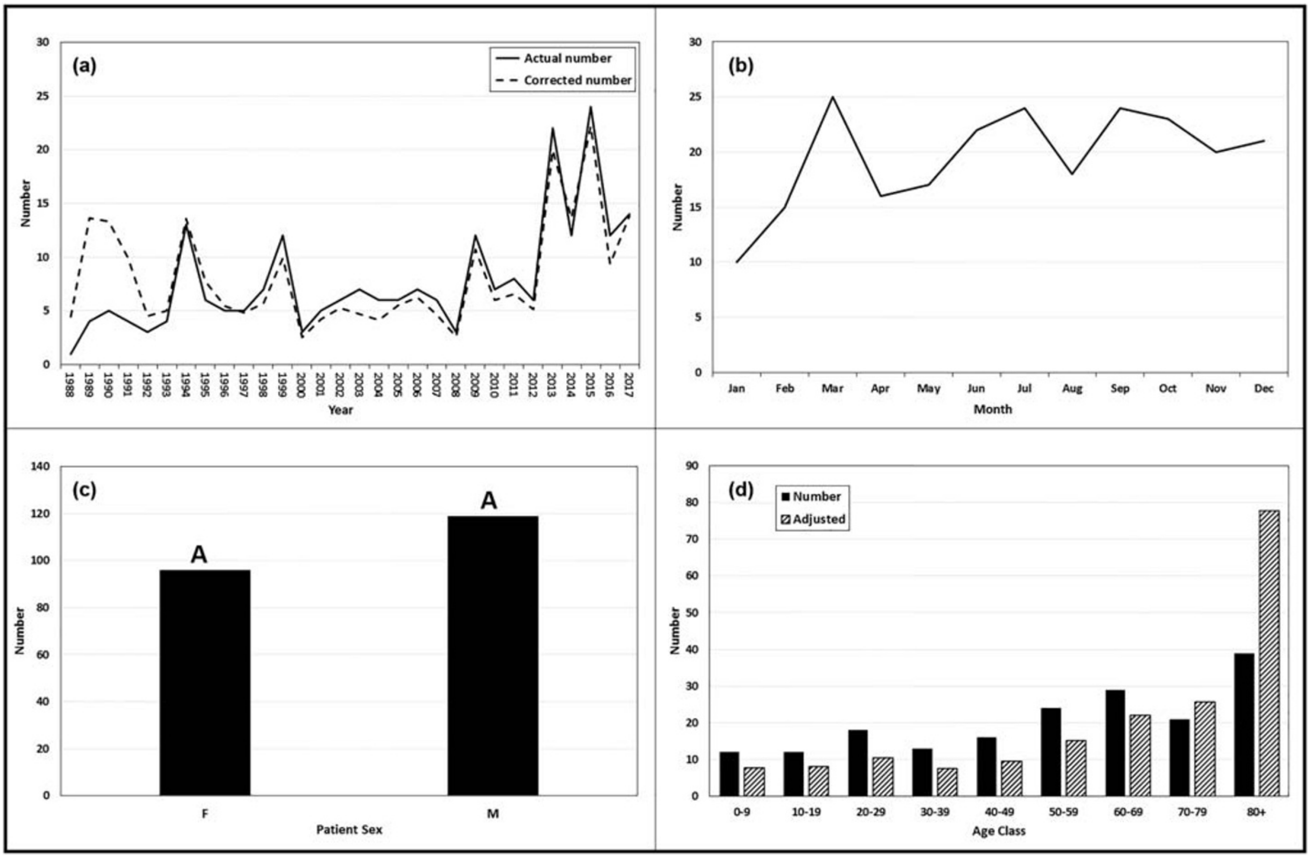

Fig. 9. Trends of specimens where scabies was requested but no evidence for scabies was found were sent to the Department of Medical Entomology for identification, 1988–2017. (a) Submissions by year; solid line represents actual number, and dashed line represents corrected number (see text). (b) Submissions by month. (c) Submissions by female (F) vs. male (M) patients. Note that the letter next to the bar graph denotes the statistical relationship; the same letters indicate no statistical difference. (d) Patient age classes; number = actual number of specimens, adjusted = adjusted for population numbers of the particular age class. The *Y*-axis is the same for actual and age adjusted numbers.

appearance of an allergic dermatitis-type reaction in humans (Nagaratnam *et al*. 2019). Considerably more women submitted *O. bursa* samples than men, almost 50% more (Fig. 3c). Finally, the age classes (Fig. 3d) show a near normal distribution, with a peak in the middle years of 30–39, which did not change substantially when adjusted for population figures.

Other common mites included scabies (this is discussed below), various mites associated with stored food products and dust mites (42 submissions, Table 2). The latter is not surprising considering the ubiquitous nature of *Dermatophagoides pteronyssinus* and other dust mites being widespread in homes (Russell 2001). Another *Ornithonyssus* submitted on 29 occasions was the rat mite *Ornithonyssus bacoti*. This species is commonly misidentified as *O. bursa*, which can present a serious challenge to the patient (see Case Study CS1 in the Supporting Information). *Ornithonyssus bursa* involves bird management, whereas *O. bacoti* involves rodent control, and misidentification will result in the incorrect control program being implemented. The two species are superficially similar morphologically but can be distinguished by the length of the setae on the dorsal plate as well as the different dimensions of this plate. The setae on the dorsal plate of *O. bursa* are shorter than those on the periphery of the body, whereas the setae on *O. bacoti* are more plentiful and uniformly sized over the body (Fig. S4).

Bed bugs

Prior to 2000, the Department had only received 16 samples of bed bugs (*Cimex* spp.), and at that stage, no examples of the tropical bed bug *C. hemipterus*, with all specimens being the common bed bug, *Cimex lectularius*. This changed in 2004 when in 1 year the Department received 36 separate samples (Fig. 4a). Since then, presumably most pathology groups are now undertaking their own identification of the species as numbers submitted to our laboratory have since declined in spite of surveys showing that bed bug numbers had still been on the rise (Doggett & Russell 2008). Over the 30 year period, there have been 149 submissions; of these 132 were *C. lectularius* and 17 *C. hemipterus*. Bed bugs represented the third most common group of submitted arthropods. The peak in submissions coincided with the recognition of a global resurgence in bed bugs (Doggett *et al*. 2004, 2011, 2018a, 2018b; Doggett & Cains 2018; Doggett & Russell 2008; Lee *et al*. 2018), and data from the identification service led to the first published evidence of the resurgence (Doggett *et al*. 2004). A wealth of evidence indicates that insecticide resistance was the trigger for the global bed bug resurgence (Dang *et al*. 2014, 2015a, 2015b, 2015c, 2017; Doggett *et al*. 2018a, 2018b; Lilly *et al*. 2015, 2016a, 2016b, 2018). Around the time of the peak in submissions, *C. hemipterus* was

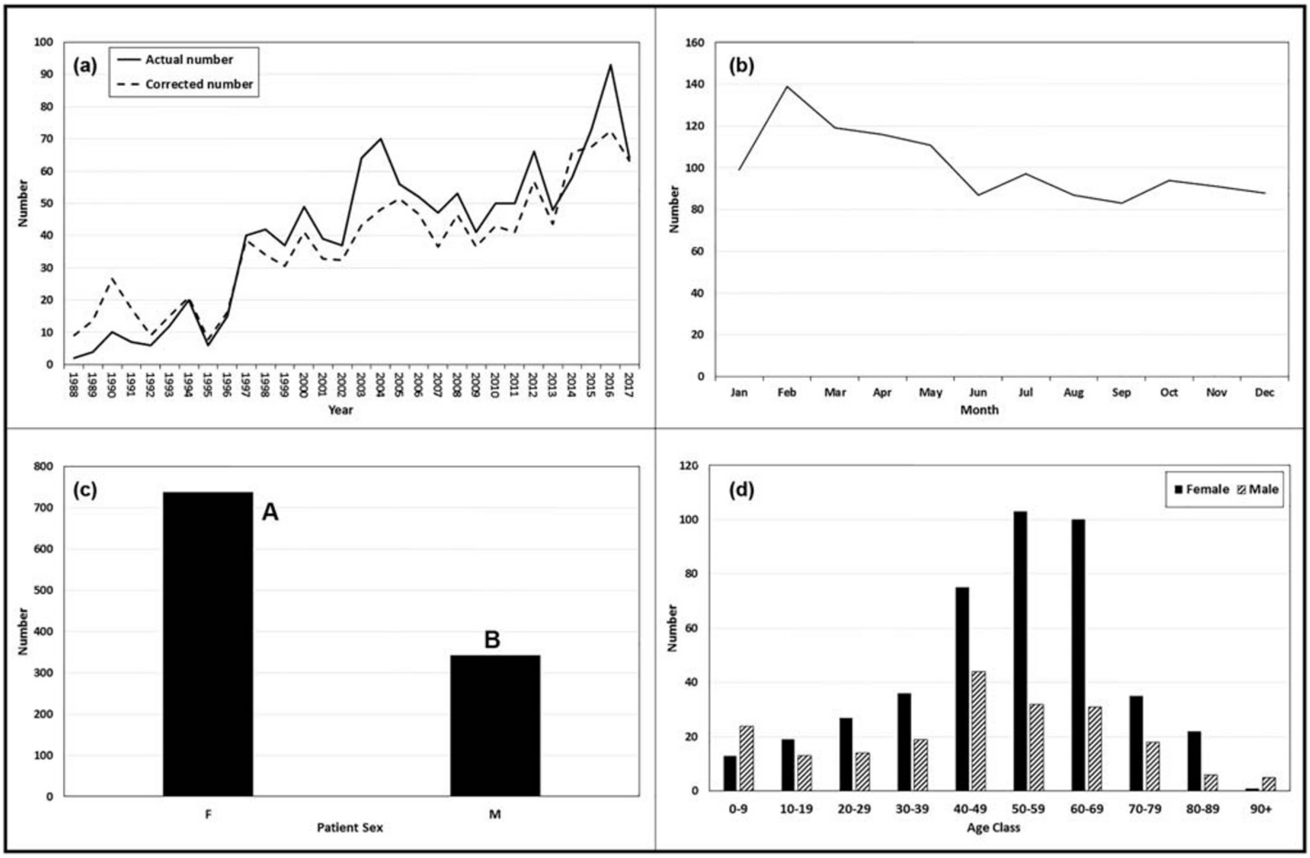

Fig. 10. Trends of specimens where there was no evidence of any arthropod of medical importance were sent to the Department of Medical Entomology for identification, 1988–2017. (a) Submissions by year; solid line represents actual number, and dashed line represents corrected number (see text). (b) Submissions by month. (c) Submissions by female (F) vs. male (M) patients. Note that the letter next to the bar graph denotes the statistical relationship; different letters indicate a statistical difference. (d) Patient age classes; the solid bar represents the number of female patients, and the hatched bar represents the number of male patients. Note that population-adjusted numbers are not included to simplify the graph.

recognised for the first time from Australia (Doggett *et al*. 2003), and this is discussed in detail later in the text. Like many other insects, submissions of bed bugs declined during the winter months (Fig. 4b), and this is in accordance with surveys undertaken on seasonal activity (Doggett *et al*. 2011; Doggett & Russell 2008). Submissions from males were slightly higher than females (Fig. 4c) but not significantly so; however, there was a major peak in the age classes of 30–49 compared with the other age groups, in both the actual numbers and population-adjusted data (Fig. 4d).

It is assumed that other pathology groups are not identifying bed bugs to the species level. This is unfortunate as the two species possess enough anatomical difference that there are implications for control programs. In the case of *C. hemipterus*, this species possesses a higher number of tenent hairs on the tibial pad, which provides them with greater grip for climbing smooth surfaces compared to *C. lectularius* (Dae-Yun *et al*. 2017). Pit-fall traps are frequently used for the monitoring of *C. lectularius* (Doggett 2013a), and these traps are less effective and unreliable for the tropical species. The key distinguishing feature to separate the two species is based on the pronotum width. In *C. hemipterus*, the pronotum is less than 2.5 times as wide as it is as long (Usinger 1966). The pronotum of *C. lectularius* appears as a lateral flange, and this is evident in stages from around the fourth instar to the adults (Fig. S5).

Moth flies

The fourth most common specimens were moth flies (Psychodidae; also called drain flies) from the genus *Clogmia* (135 submissions). When identified to species, all were *Clogmia albipunctata*. Regarding their clinical significance, there is a report that the adults of this species can pass pathogens mechanically (Faulde & Spiesberger 2013), and a number of publications detail both urinary and intestinal myiasis with the larval stage (El-Badry *et al*. 2014; El-Dib *et al*. 2017; Hjaija *et al*. 2018; Mokhtar *et al*. 2016; Smith & Thomas 1979). All of these papers suggest that *Clogmia* are of medical importance. However, there are doubts about the myiasis papers as the larvae of *Clogmia* breed in biofilms such as that which occurs under toilet rims (authors, *personal observation*). In fact, with regard to the clinical notes that have accompanied the specimens to our Department, most state that they were found in the toilet, or were passed in the faeces or urine. It appears that *Clogmia* really is of little clinical significance, based on our compiled data.

Interestingly, and in contrast with other specimens, *Clogmia* submissions have steadily increased over the years for reasons that are not obvious (Fig. 5a). Figure 5b shows a seasonal pattern of reduced activity in the cooler months, which would be expected as the fly breeds in and around the home and thus reflect insect activity generally. While the number of female and male patients is not statistically different (Fig. 5c), submissions from men are slightly higher. We have noted that many specimens of *Clogmia* come from younger adult males. Overall, the age class of patients submitting specimens follows a near normal distribution (Fig. 5d), although there is a drop in submissions from the 50–59 age group, which may be an artefact due to the small numbers.

Head lice

Head lice *P. capitis* were the next most commonly submitted group with 105 submissions. Considering how common head lice infestations are these days (Falagas *et al*. 2008; Speare & Beuttner 2008), this appears to be a small number of submissions. Over the 30 years, submissions fluctuated on an annual basis with no real trend (Fig. 6a). Submissions peak during late summer (Fig. 6b), the time when children return to school after the summer break. The number of specimens from females was around three times that of males (Fig. 6c), which is in agreement with most studies that show that young girls are more likely to develop a head lice infestation than young boys (Counahan *et al*. 2004; Falagas *et al*. 2008; Speare & Beuttner 2008). Children under 10 years of age were more likely to develop an infestation (Fig. 6d), which is also in agreement with the above studies. Interestingly, the population age-adjusted data show a second peak in the elderly.

Pubic lice

Phthiraptera was the next most frequently submitted group of arthropods. Pubic lice, *P. pubis*, accounted for 91 specimens. This number was too low to infer any major trends over the 30 year period (Fig. 7a), and none were evident. This is in spite of the numerous internet articles and some published papers that have suggested that *P. pubis* are declining in number due to the modern propensity of adults to remove part or all of their pubic hair (Dholakia *et al*. 2014). As *P. pubis* lives in such close contact with humans (on the body), it is not a surprise that a seasonal trend was not evident (Fig. 7b). However, a significantly higher number of specimens were submitted by males than females (Fig. 7c). There could be three reasons for this trend. Men tend to be more promiscuous, having more sexual encounters than women (Mitchell *et al*. 2019), thereby increasing the risk of acquiring an infestation. Men are less likely to groom and completely remove their pubic hair than women (Butler *et al*. 2015), and tend to be more hairy than women. Regarding age classes of patients (Fig. 7d), it was adults in the years of 20–49 who more frequently submitted samples. It does appear confronting that a number of children under 10 have presented with *P. pubis* infestations; in fact, all were under 7 years of age. In children of this age, *P. pubis* tends to occur on other areas of the body where the hair is coarser, such as on the eye lashes (Klaus *et al*. 1994). *Pthirus pubis* and *P. capitis* (head lice) are very easy to distinguish by the presence of the crab-like claws on the pubic lice, evolved to grasp the coarser pubic hair. However, the eggs (nits) are more challenging to separate taxonomically (and often only the egg is received), although they can be separated on the shape of the operculum and amount of glue the louse uses to cement the egg to the hair shaft (Fig. S6). See also Case Study CS2 in the Supporting Information.

Scabies

There were 57 submissions of scabies mite *S. scabiei*, a number too low to notice any obvious trend over the 30 year period (Fig. 8a). However, a seasonal trend was very evident with a peak in winter months (Fig. 8b), which is in contrast to most of the other arthropods. There was no statistical difference in submissions from females and males (Fig. 8c), although *S. scabiei* was far more frequent in the older age classes, from 70 and up (Fig. 8d), and this was emphasised even more with the population age-adjusted data. Our data show that scabies tends to occur more commonly in elderly patients who may not be able to look after themselves, and the mite is rare in otherwise healthy individuals.

It is interesting to compare the *S. scabiei* data with requests for scabies that proved negative for the mite (Fig. 9). There were over four times more specimens that were negative to scabies than those that were actually positive (235 vs. 57). Since 2008, there has been a gradual rise in the number of negative scabies specimens (Fig. 9a), there is no obvious seasonal trend (Fig. 9b), there were slightly more males than females (although not statistically different, Fig. 9c), but there was a strong tendency towards older patients (Fig. 9d), although not as strong as with the scabies positive group. Based on our data, the medical community should be more targeted in their requests for testing patients to avoid unnecessary Medicare expense and over-servicing.

No evidence

The final category where there were 50 or more specimens was also the largest category recorded over the 30 years of the service (1211 submissions, Fig. 10). These were specimens that contained no evidence of an arthropod of medical importance. Typically, clinical notes may state 'itch', 'biting', or 'off body' or have some other indication that the patient believed they were being infested or attacked by an arthropod such as a mite. What is interesting are the trends associated with such specimens. Since the start of the service, there has been a gradual annual increase in the number of such specimens (Fig. 10a). Seasonally, there is not a big decline during the cooler months as per other categories that contain arthropods (Fig. 10b). Women account for more than double that of men (Fig. 10c), while for the age classes, women in the years of 40–69 dominate, while for men, the peak is in the 40–49 age group (Fig. 10d). Most of the obvious trends cannot be readily explained. Why such specimens should be undergoing a continual annual increase when none of the other groups have is unknown.

Table 2 Specimens (no. >5) submitted to the Department of Medical Entomology, 1988–2017, in descending order of frequency

Species name (Family: Order)	Common name	No.
Ixodes holocyclus (Ixodidae: Acari)	Australian paralysis tick	708
Ornithonyssus bursa (Macronyssidae: Mesostigmata)	Bird mite	506
Clogmia spp. (Psychodidae: Diptera)	Moth flies	135
Cimex lectularius (Cimicidae: Hemiptera)	Common bed bug	132
Pediculus capitis (Peduculidae: Phthiraptera)	Head lice	105
Pthirus pubis (Pthiridae: Phthiraptera)	Pubic lice	91
Sarcoptes scabiei (Sarcoptidae: Sarcoptiformes)	Scabies	57
Dermatophagoides spp. (Pyroglyphidae: Acariformes)	Dust mites	42
Ctenocephalides felis (Pulicidae: Siphonaptera)	Cat flea	41
Lampona spp. (Lamponidae: Araneae)	White-tailed spiders	37
Liposcelis spp. (Liposcelididae: Pscocoptera)	Booklice	29
Ornithonyssus bacoti (Macronyssidae: Mesostigmata)	Rat mite	29
Thaumastocoris spp. (Thaumastocoridae: Hemiptera)	Plant bugs (various)	29
Dermatobia hominis (Oestridae: Diptera)	Human bot fly	28
Anthrenus verbasci (Dermestidae: Coleoptera)	Variegated carpet beetle	26
Misgolas spp. (Idiopidae: Araneae)	Trapdoor spiders	24
Amblyomma triguttatum (Ixodidae: Acari)	Kangaroo tick	23
Calliphora spp. (Calliphoridae: Diptera)	Blow flies	23
Isopoda (Order: Isopoda)	Slaters	21
Stegobium paniceum (Ptinidae: Coleoptera)	Drugstore beetle	20
Vespula germanica (Vespidae: Hymenoptera)	German wasp	19
Apis mellifera (Apidae: Hymenoptera)	Honey bee	18
Cimex hemipterus (Cimicidae: Hemiptera)	Tropical bed bug	17
Eriophora spp. (Araneidae: Araneae)	Orb weaver spiders	17
Tunga penetrans (Hectopsyllidae: Siphonaptera)	Chigoe flea	17
Ixodes spp. (Ixodidae: Acari)	Ticks (various)	16
Lycosa spp. (Lycosidae: Araneae)	Wolf spiders	16
Lucilia cuprina (Calliphoridae: Diptera)	Australian sheep blow fly	15
Toxorhynchites speciosus (Culicidae: Diptera)	Mosquito (no common name)	15
Badumna insignis (Desidae: Araneae)	Black house spider	14
Calliphora augur (Calliphoridae: Diptera)	Lesser brown blow fly	14
Cordylobia anthropophaga (Calliphoridae: Diptera)	Tumbu fly	14
Tyrophagus putrescentiae (Acaridae: Sarcoptiformes)	Mould mite	14
Atrax robustus (Atracidae: Araneae)	Sydney funnel web spider	13
Gibbium psylloides (Ptinidae: Coleoptera)	Spider beetle	13
Lasioderma serricorne (Ptinidae: Coleoptera)	Tobacco beetle	13
Lucilia spp. (Calliphoridae: Diptera)	Blow flies	13
Eristalis spp. (Syrphidae: Diptera)	Drone fly	12
Anthrenocerus australis (Dermestidae: Coleoptera)	Australian carpet beetle	11
Dermatophagoides pteronyssinus (Pyroglyphidae: Acariformes)	House dust mite	11
Ixodes tasmani (Ixodidae: Acari)	Common marsupial tick	11
Pheidole megacephala (Formicidae: Hymenoptera)	Coastal brown ant	11
Rhipicephalus sanguineus (Ixodidae: Acari)	Brown dog tick	11
Demodex folliculorum (Demodicidae: Trombidiformes)	Follicle mite	10
Eriophora transmarina (Araneidae: Araneae)	Australian garden orb weaver spider	8
Euproctis edwardsi (Lymantriidae: Lepidoptera)	Mistletoe brown-tail Moth	8
Ixodes ricinus (Ixodidae: Acari)	Castor bean tick	8
Haemaphysalis longicornis (Ixodidae: Acari)	Asian longhorned tick	7
Misgolas rapax (Idiopidae: Araneae)	Sydney brown trapdoor spider	7
Aedes notoscriptus (Culicidae: Diptera)	Common backyard mosquito	6
Atrax spp. (Atracidae: Araneae)	Funnel web spiders	6
Haemaphysalis bancrofti (Ixodidae: Acari)	Wallaby tick	6
Lepidoglyphus destructor (Glycyphagidae: Acaridae)	Mite (no common name)	6
Lepinotus spp. (Trogiidae: Pscocoptera)	Booklice	6
Leptocneria reducta (Lymantriidae: Lepidoptera)	White cedar moth	6
Nysius vinitor (Lygaeidae: Hemiptera)	Rutherglen bug	6
Polistes spp. (Vespidae: Hymenoptera)	Paper nest wasps	6
Sitophilus oryzae (Curclionidae: Coleoptera)	Rice weevil	6
Technomyrmex albipes (Formicidae: Hymenoptera)	White-footed house ant	6
Amblyomma moreliae (Ixodidae: Acari)	Tick (no common name)	5
Amblyomma spp. (Ixodidae: Acari)	Ticks (no common name)	5
Culex quinquefasciatus (Culicidae: Diptera)	Southern (or Brown) house mosquito	5
Dermanyssus gallinae (Dermanyssidae: Mesostigmata)	Poultry mite	5

(*Continues*)

Table 2 (Continued)

Species name (Family: Order)	Common name	No.
Eristalis tenax (Syrphidae: Diptera)	Drone fly	5
Latrodectus hasselti (Theridiidae: Araneae)	Redback spider	5
Lucilia sericata (Calliphoridae: Diptera)	Common green bottle fly	5
Plodia interpunctella (Pyralidae: Lepidoptera)	Indian meal moth	5

One aspect that may be relevant relates to the media and how the public is subjected to advertising for home cleaning and pest control products. Cleaning products are often promoted as killing 99.99% of bacteria, and insects are depicted as germ carrying entities that can harm people. There are suggestions that society today is obsessed with cleanliness, and paranoia is on the rise (Flora 2016; Freeman & Freeman 2009). Thus, any hint of an itch or a bite may be associated with some mysterious arthropod infestation, which is then acted upon by the patient by taking samples to their medical practitioner for analysis, or the patient may even self-harm (see Case Study CS3 in the Supporting Information).

In speaking with patients from this group, one aspect is quite apparent, the overuse of insecticides and topical creams. It is not unusual for multiple pest controllers to be employed and many cans of total release insecticidal aerosols (bug bombs) to be set off in the homes. Most household insecticides contain pyrethroids, and contact with the skin can result in paraesthesia, an itching or tingling sensation, not unlike an insect crawling over the skin (Cagen *et al*. 1984; Flannigan*et al*. 1985; Bradberry *et al*. 2005). Similarly, so-called 'natural' products such as tea tree oil and other essential oils can cause skin irritation and allergies (Monthrope & Shaw 2004; Rubel *et al*. 2007; Rutherford *et al*. 2007; Southwell *et al*. 1997). Any initial cause of irritation may be perpetuated by the overuse of these chemicals. Interestingly, the patients generally give little thought to the dangers of the haphazard and often prolonged usage of these insecticides in their home and the products they apply to their skin.

The higher number of women, especially in the age group most affected of 40–69 (Fig. 10d), could relate to symptoms of formication associated with menopause (Coope *et al*. 1975). Formication is the sensation of insects crawling under the skin and in menopause relates to a decline in the levels of oestrogen, which is important for skin health (Lillis 2018). As the condition can be alleviated by a number of therapies including hormone replacement therapy (Lillis 2018), the testing of such patients for hormone levels may be beneficial.

Another possible explanation is the rise in drug usage. The drug methamphetamine is known to produce a condition called 'meth' or 'ice' bug, with a sensation akin to insects crawling under the skin (Frieden 2006). Evidence suggests that in Australia, the incidence of methamphetamine use in addicts has increased between 2010 and 2016 (Australian Government 2017). The drug usage of patients is not included on pathology requests forms owing to privacy laws, and thus we have no evidence to suggest the rise in 'no evidence' specimens is related to drug use.

Whatever the reason for the growing number of arthropod negative specimens, the fact that they are rising at such a rate warrants further investigations.

A large percentage of the samples with arthropods of no public health importance do contain various arthropods, which represent normal household and backyard fauna. A number of clients have tried to associate these to their medical condition. The most common maligned arthropods are amphipods, thaumastocorids, psocids, moth flies (both adult and larval stages), and rat-tailed maggots (Syrphidae). Species within Collembola, Psocoptera and Coleoptera (in particular Dermestidae), are repeatedly singled out as the cause of patients' ailment. Where possible, clients are requested to submit their entomological samples through their general practitioner, who then receives the result of the identification. It is the clinician who can best manage a patient's health, particularly in situations where there could be underlying psychological issues causing the patient to submit multiple samples, such as delusionary parasitosis, also known as Ekbom syndrome (Hinkle 2010, 2011).

Miscellaneous groups

Beyond the more common specimens discussed above, a wide variety of different arthropods were submitted as noted by the diversity of the different taxa represented (25 orders, 188 families, 177 genera and 170 species). A brief review of some of these follows.

Some 95 specimens of Lepidoptera were submitted, the most common being Pyralidae (31 submissions), notably the Indian meal moth, *Plodia interpunctella*. In fact, many of the patient request forms ask if these insects were 'worms'.

The other lepidopteran group that was occasionally submitted were the urticarial caterpillars, particularly from the families Lymantriidae and Arctiidae. Australia has a variety of urticating caterpillars that have the potential to cause medical conditions including urticaria, blistering lesions and extreme irritation to individuals who come into contact with them. The white cedar moth (*Leptocneria reducta*: Lymantriidae) has two generations each year, appearing in late spring and autumn. After exhausting their food source, the common white cedar tree (*Melia azedarach*), processionary caterpillars can enter domestic dwellings, cars and other building structures in their search for food or suitable pupation sites. This movement of caterpillars into homes is of great cause for concern for the occupants (Southcott 1978). The caterpillars are known to cause dermatitis in some individuals who make contact. There are other species of urticating caterpillars that pose health risks. The main species for concern are the larval stage of *Chelepteryx collesi* (Balit *et al*. 2004) and *Euproctis edwardsi* (Balit *et al*. 2001). The latter species is reported to be the most important cause of caterpillar dermatitis within Australia (Southcott 1978). Contact with both these species can result in medical care being sought. In addition, Australia has many species of cup moth (Limacodidae). These often brightly coloured caterpillars can inflict a painful sting from their irritating spines. Cup moth caterpillars feed on a wide variety of fruit and ornamental plants in many Australian backyards. See also Case Study CS4 in the Supporting Information.

Several species of Psocoptera were sent with some 70 submissions. The most common of these belonged to the genus *Liposcelis* (27). Psocoptera are cosmopolitan inhabitants of domestic households, do not bite and are considered of little medical importance, although on occasion they have been associated with triggering allergies (Turner *et al*. 1996). Unfortunately, Psocoptera are commonly referred to as 'booklice', due to their association with paper products, especially by the pest control industry. As a consequence, we have noted that some members of the public believe themselves or their home to be infested with 'lice', which can lead to over use of pediculicides and pesticides.

There were 30 submissions of Thysanoptera. Species of thrips can come into contact with humans through the contamination of laundered clothes hung outside to dry or from direct contact with plants. These small insects frequently occur in people's backyards and may be present in vast numbers. The plague thrip, *Thrips imaginis*, was the most frequently submitted species. This species was responsible for the closure of a shopping centre in Queensland during 2011 when large numbers of this insect were distributed through the shopping complex via air conditioning ducts (unpublished data).

Some insect specimens that are seen as the source of an affliction are repeatedly confused with medically important arthropods that appear very similar in shape and form. For example, sap sucking bugs from the family Thaumastocoridae that infest the upper canopy of native trees and shrubs have been repeatedly incorrectly labelled as head lice. Over the years, we have received some 30 separate samples of this group, and typically they have been collected from the hair of children. Cockroach nymphs have been repeatedly submitted as evidence for a bed

Table 3 Samples exotic to Australia submitted to the Department of Medical Entomology, 1988–2017, where the source and/or the location was recorded

Species	Common name	Body location or source (number)	Location (number)
Flies (Diptera)			
Cordylobia anthropophaga	Tumbu fly	Body (4), leg (2), thigh (2), back (1), buttock (1); skin (1)	Africa (2), Congo (1), Gabon (1), Kenya (1), Nigeria (1), Uganda (2), Zambia (1), Zimbabwe (1), unknown (2)
Cordylobia rodhaini	Lund's fly	Arm (1), lower back (1), thigh (1), unknown (1)	Africa (3), Ghana (1)
Dermatobia hominis	Human bot fly	Abdomen (1), ankle (1), arm (1), back (2), body (4), buttock (2), elbow (1), foot (1), leg (1), lesion (1), scalp (4), shoulder (1), sinus (1), skin (4), wound (1), unknown (2)	Amazon (2), Belize (2); Bolivia (5), Brazil (1), Mexico (2), Peru (6), South America (9)
Fleas (Siphonaptera)			
Tunga penetrans (Hectopsyllidae: Siphonaptera)	Chigoe flea	Foot (7), toe (6), toe nail (1)	Africa (3), Brazil (1), Burundi (1), Central Africa (1), Kenya (2), Madagascar (1), South America (1), Venezuela (1), Zimbabwe (1), unknown (2)
Bed bugs (Hemiptera)			
Cimex hemipterus†	Tropical bed bug	Belongings (1)	China (1)
Lice (Pthiraptera)			
Pediculus humanus	Body lice	Aircraft passenger clothes (1)	USA (1)
Ticks (Ixodidae)			
Dermacentor andersoni (Ixodidae: Acari)	Rocky Mountain wood tick	Human (1)	Unknown (1)
Haemaphysalis bispinosa (Ixodidae: Acari)	No common name	Balsawood flowers (1)	India (1)
Ixodes persulcatus (Ixodidae: Acari)	Taiga tick	Human (1)	Unknown (1)
Ixodes ricinus (Ixodidae: Acari)	Castor bean tick	Dog (5), cat (2)	Finland (1), Germany (2), Sweden (1), Switzerland (1), UK (1)
Ixodes scapularis (Ixodidae: Acari)	Black legged tick	Dog (1)	USA (1)
Rhipicephalus sanguineus†	Brown dog tick	Imported goods (1)	Indonesia (1)
Centipedes (Geophilimorpha)			
Order: Geophilimorpha	Centipede	Baby anus (1)	Fiji (1)

†Endemic non-indigenous specimens that were brought into Australia via travellers.

Table 4 New records of medically important arthropods for Australia, 1988–2017

Species	Year	Details of where found
Aleuroglyphus ovatus†	1996	Animal house facility, Westmead (Geary *et al.* 2000)
Cordylobia rodhaini†	1997	Patient, ex east Africa (Geary *et al.* 1999)
Cimex hemipterus†	1998	Café, Bundaberg (Doggett *et al.* 2003)
Haemaphysalis bispinosa†	2003	Balsa wood flowers, ex India
Ixodes ricinus†	2004	Ex dog, UK
Ixodes scapularis†	2006	Ex dog, USA
Ixodes ornithorhynchi‡	2015	Ex patient, Victoria
Ixodes persulcatus†	2016	Ex patient, Eastern Europe
Dermacentor andersoni†	2016	Ex patient, USA

†New record for Australia
‡First record of this tick species biting humans

bug infestation, especially when bed bugs were under the media spotlight during the end of the first decade of the 21st century.

Non-entomological specimens are submitted on occasions for analysis. One particularly interesting sample consisted of small white segments that had been collected from a bed, where the female occupant repeatedly complained of bites. After rehydration and examination of the segments, the specimens were identified as segments of the cestode species *Dipylidium caninum* (Dipylidiidae), often referred to as the flea tapeworm. Further questioning revealed the female occupant regularly slept with two cats in her bed that were infested with the common cat flea *C. felis*, which is the main vector. Another very curious non-entomological specimen is detailed in the Supporting Information (Fig. S7).

Exotic species

Our pathology service has identified a number of arthropods that came from travellers from overseas (Table 3). Many of these were the larvae of myiasis flies including *D. hominis* (26 specimens) from South America, and *C. anthropophaga* (13) and *C. rodhaini* (3) from Africa. Typically, travellers return home and present to their medical practitioner with an unusually large painful lesion, often weeping, normally on the arm or legs. Typically the larvae are surgically excised. Most larvae tend to be the later instars, notably third instars. For the myiasis flies, it is useful that the patient's travel history is obtained, as these details can aid in confirmation of the specimen's identification especially if damaged. For *Dermatobia*, patients who have acquired this fly will have recently travelled through the Neotropical areas of South America where the species is indigenous from Mexico, through Central America, to Paraguay and northeast Argentina (University of Florida 2008). *Cordylobia* may infest travellers while visiting the African continent but are less frequently submitted to our pathology service (Geary *et al.* 1999).

Two of the most important species for concern are the dipteran species *Chrysomya bezziana* (Old World screwworm fly) and *Cochliomyia hominivorax* (New World screwworm fly) (Spradbery 2002, 2017) that are major economic pests. To date, these species have not been detected by our pathology service.

Another exotic arthropod that penetrates the skin is the flea *T. penetrans* (14). The egg of this flea is often the only evidence of the infestation, but occasionally, a fragment or the entire adult female flea is excised from the patient's subcutaneous tissue of the feet or between the toes. The adult female flea, which measures only 1 mm before penetrating into the skin, is thought to be the world's tiniest flea species and is endemic in the tropical and subtropical regions of North and South America, the West Indies and tropical Africa (Goddard 2000; Service 1980).

Another group of exotics well represented were the ticks, with some very important vectors of human pathogens including *Ixodes ricinus* (7, ex Europe), *Ixodes persulcatus* (1, ex Europe), *Ixodes scapularis* (1, ex USA), *Dermacentor andersoni* (1, ex USA), and *Haemaphysalis bispinosa* (1, ex India). Most were detected within a quarantine facility and sent to our laboratory by members of the Australian Quarantine and Inspection Services (now called the Department of Agriculture, Water and the Environment).

Many of these exotics were new records for Australia (Table 4), and over the 30 years of the study, two species became established. The tropical bed bug *C. hemipterus* was first recognised after being collected from a café in Bundaberg, Queensland, during 1998 (Doggett *et al.* 2003). However, a later review of museum reference collections from laboratories around Australia revealed specimens of *C. hemipterus* dating back to 1991 from Katherine and 1994 from Darwin in the Northern Territory, which had been misidentified as *C. lectularius* (Doggett *et al.* 2011; Doggett & Cains 2018). The other species that appears to have established during the 30 year period is the brown-legged mite *A. ovatus*. This was first detected in 1996 from animal feed produce. As this was sourced locally, it has to be assumed that the mite is widely established. For the other exotics detected, the risk of establishment is probably low, as relatively few specimens have been imported (notably the myiasis flies and ticks), and quarantine requirements mean that exotic ticks are detected on pets before the animals are released to their owners.

It is also worth reviewing what specimens were not recorded over the 30 years. The human flea *Pulex irritans* is a cosmopolitan species that has occurred widely in homes in Australia (Dunnet & Mardon 1974; Lee 1975). However, not one specimen was received, and this species appears to be at least very rare in our region, and perhaps no longer present. In reviewing our laboratories' reference collection, the most recent specimens of

P. irritans date back to the early 1950's; 1951 from Sydney, 1952 from Hornsby and 1953 from Randwick (unpublished data). Dunnet and Mardon (1974) reported several slightly later infestations including Sydney in 1954, Canberra in 1954 and 1957, a Sydney to Brisbane bus in 1957, and the most recent being Toolom (NSW) in 1961.

There was only one submission of the body louse *Pediculus humanus* originating from Australia. This particular case was of an elderly man whose body was received at Westmead Hospital's mortuary in 1992. His clothes literally contained thousands of lice. The only other submission of *P. humanus* was in 2008 in association with an arriving passenger from Boston, USA. *P. humanus* is another cosmopolitan species that appears to have become very rare and perhaps locally extinct in parts of Australia.

Another species that has become less common is the cat flea *C. felis*. In fact there was not one specimen submitted over 2014–2017. Prior to this, some 39 separate samples were received. It is probable that the anti-parasitic treatments of pets have contributed to the decline in the cat flea, although no systematic study in pets has been undertaken in Australia for some years.

Benefits of the identification service

As can be seen, the pathology service has resulted in the identification of a vast range of arthropods; however, the service has provided more benefits than just identification. Over time, the samples have provided a valuable insight into the pest species that affect the community, as well as those which are most abundant and when, and which age groups are at the greatest risk for a particular pest.

One constant throughout this time span has been the problems that invertebrates cause to humans. Arthropods are a normal part of our environment, and their mere presence in our home environment is sufficient reason for some people to seek assistance. With a rapidly changing climate, the ever-increasing spread of human habitation into rural areas, and the increasing number of travellers, there is likely to be increasing encounters with medically important species. Therefore it is imperative that the expertise is maintained to rapidly identify, evaluate and provide expert advice on the implications and management of arthropods of medical importance.

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SUPPORTING INFORMATION

Additional supporting information may/can be found online in the supporting information tab for this article.

Figure S1. An example of a sectioned tick sent for identification. The body size, cuticle and cuticular pattern can provide an indication that it is a tick. Sometimes legs and the head may be present. Length – 3 mm, stain used not stated.

Figure S2. Photographs of live female *Ixodes holocyclus* (left) and *I. cornuatus* (right), not to scale. Note the lighter colouration of the middle pairs of legs in *I. holocyclus* (indicated by arrows) compared with the fore and hind legs. *Ixodes cornuatus* has uniformly coloured legs and tends to have a deeper, slightly reddish tinge.

Figure S3. Photographs of live male *Ixodes holocyclus* (left) and *I. cornuatus* (right), to scale. As per the females, *I. cornuatus* has all legs uniformly coloured and the body has a darker colouration, with a slight red tinge. Body length is also greater in *I. cornuatus*.

Figure S4. Images of the bird mite, *Ornithonyssus bursa* (left) and the rodent mite, *O. bacoti* (right). The arrow points to the dorsal plate (DP), showing that the setae on the plate of *O. bursa* are much shorter than those on the periphery of the body. In contrast, the length of the setae on *O. bacoti* are more uniform. This species also has more setae on the body. The dorsal plate is much wider in *O.bursa* compared to *O. bacoti*. Bar = 1 mm.

Figure S5. The various stages of the tropical bed bug, *Cimex hemipterus* (top row) and the common bed bug, *C. lectularius* (bottom row). Bar = 5 mm. The distinguishing feature is the lateral flange on the pronotum in *C. lectularius* (as indicated by the arrow), this is evident from the 3rd instar onwards. M = Male, F = Female, 5 = fifth instar, 4 = fourth instar, 3 = third instar, 2 = second instar, 1 = first instar.

Figure S6. Images of the eggs (nits) of pubic, *Pthirus pubis* (upper), and head lice, *Pediculus capitis* (lower). In *P. pubis*, the operculum (left arrow) is conical shape, being flatter in *P. capitis*, and a much heavier layer of glue (right arrow) is cemented to the hair shaft with *P. pubis*. Eggs are approximately 1 mm in length.

Figure S7. Perhaps one of the most unusual 'entomological' samples received by the Department. According to the pathology report that had accompanied the sample, the 'maggots' were recovered from the faeces of a 1-year old child. These were fake rubber maggots that the child had presumably consumed.

Table S1. Origin of specimens (when known) submitted to the Department of Medical Entomology, 1988–2017.

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Source	**Number**	**%**
Bitten or stung person	1642	32.8
On or in body (no details from where on the body)	1315	26.3
Insect ID (origin not specified)	854	17.1
Home	648	13.0
Toilet	86	1.7
Office	83	1.7
Dust	60	1.2
Garden/Outdoor	48	1.0
Food	46	0.9
Faeces	39	0.8
Hospital	32	0.6
Laboratory	30	0.6
Nursing home	25	0.5
Animal	20	0.4
Clothing	18	0.4
School	12	0.2
Water supply	12	0.2
Hotel	10	0.2
Farm	4	0.1
Insect trap	4	0.1
Child Care Centre	3	0.1

Factory	3	0.1
Septic tank	3	0.1
Shop	3	0.1
Cinema	1	<0.1
Public transport	1	<0.1

Supporting Information – Case Studies

CS1, Bird Mites: staff working on an exhibit in a large zoo were repeatedly irritated by a species of biting mite. The mite species was incorrectly identified as the rodent mite *O. bacoti* by a large museum. Rodent control measures were implemented to militate against the mite, yet there was no improvement. After several weeks of the problem continuing, specimens were sent to our Department and the mites were identified as *O. bursa*. Subsequently bird management procedures were implemented and the problem resolved. An almost reverse of this situation occurred with a patient who complained of biting mites. She presented a sample of the offending mite to her medical practitioner, who sent them to a private pathology laboratory who identified them as *O. bursa*. Bird management failed to alleviate the problem and so samples of the mite were sent to an entomology laboratory with expertise in agricultural pests, who also identified the mites as *O. bursa*. The bites continued. After several months of continual nuisance biting, the mites were submitted to our laboratory and proved to be *O. bacoti*. Rodent management was initiated and the problem solved.

CS2, Pubic Lice: a hirsute male patient admitted to emergency ward after collapsing was found to be covered in "ticks". This prompted an urgent request for identification and our Department identified the specimens as *P. pubis*. The patient's wife insisted this infestation must have been acquired when he was admitted into the Emergency Department earlier that night. This particular case highlights how many people will refuse to accept the accurate identification of an arthropod if it does not fit into their preconceived perceptions.

CS3, Delusionary Parasitosis: a female patient was convinced that she had a mite infestation along her hair line. Her husband was a machinist who made tools for a living. He made a metal tool to help her scratch along the hair line. She used the tool so much, she not only broke through the skin layer, but penetrated the skull, inducing a cerebral haemorrhage. She survived this potentially fatal infliction, but when recovered, was still convinced that she had the mite infestation. She also convinced her husband that he too was infested.

CS4, Urticating Caterpillars: At a day care facility located in a suburb of western Sydney, a teacher encouraged the children to collect and study the large number of caterpillars that had crawled into their carpeted play area. Adjacent to the day care facility was a large vacant block of land with a stand of black wattle trees (*Acacia mearnsii*) that were infested with the urticating processionary caterpillar species *Ochrogaster lunifer* (Family: Thaumetopoeidae). Occupants of the day care facility had to seek medical attention for the treatment of their skin irritations and the facility was closed for several days for decontamination (Geary, Doggett & Russell, unpublished data).

Supporting Information - Figures

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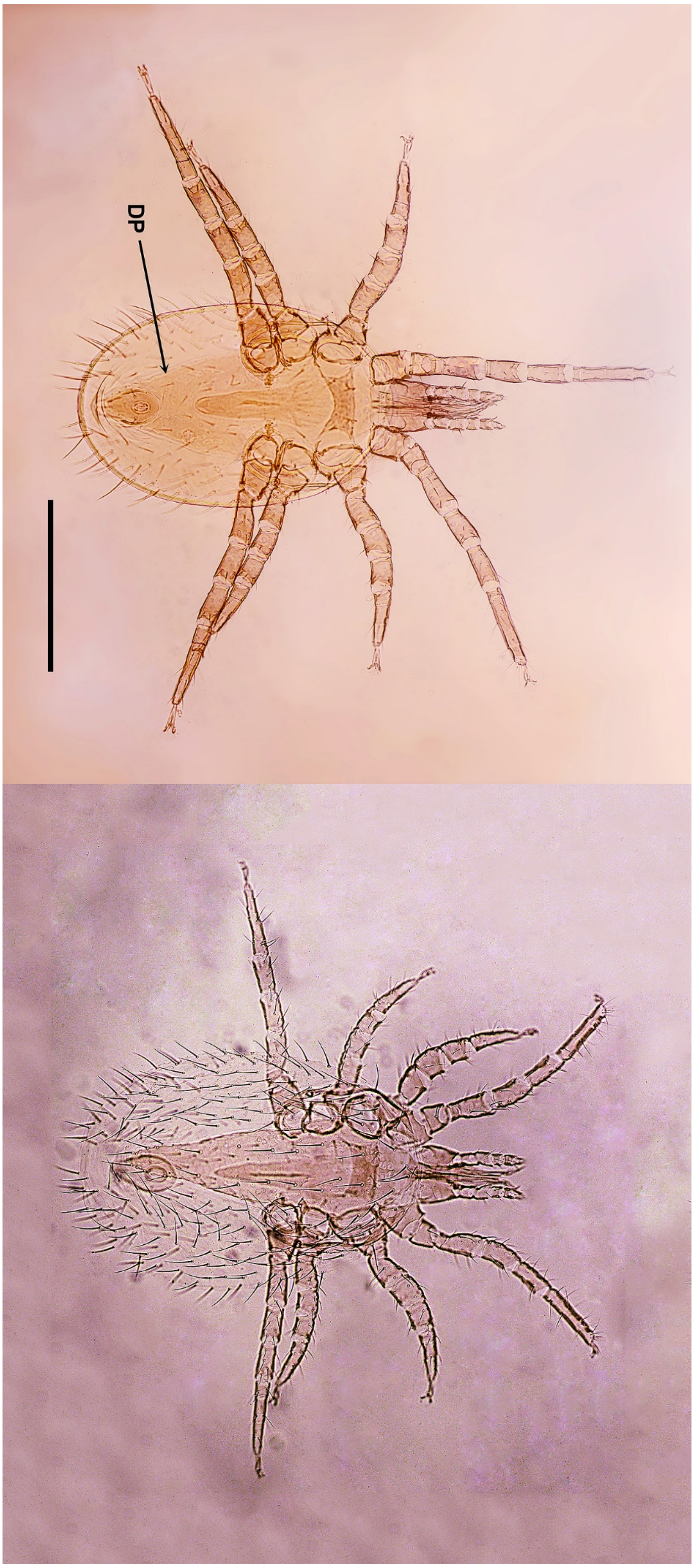
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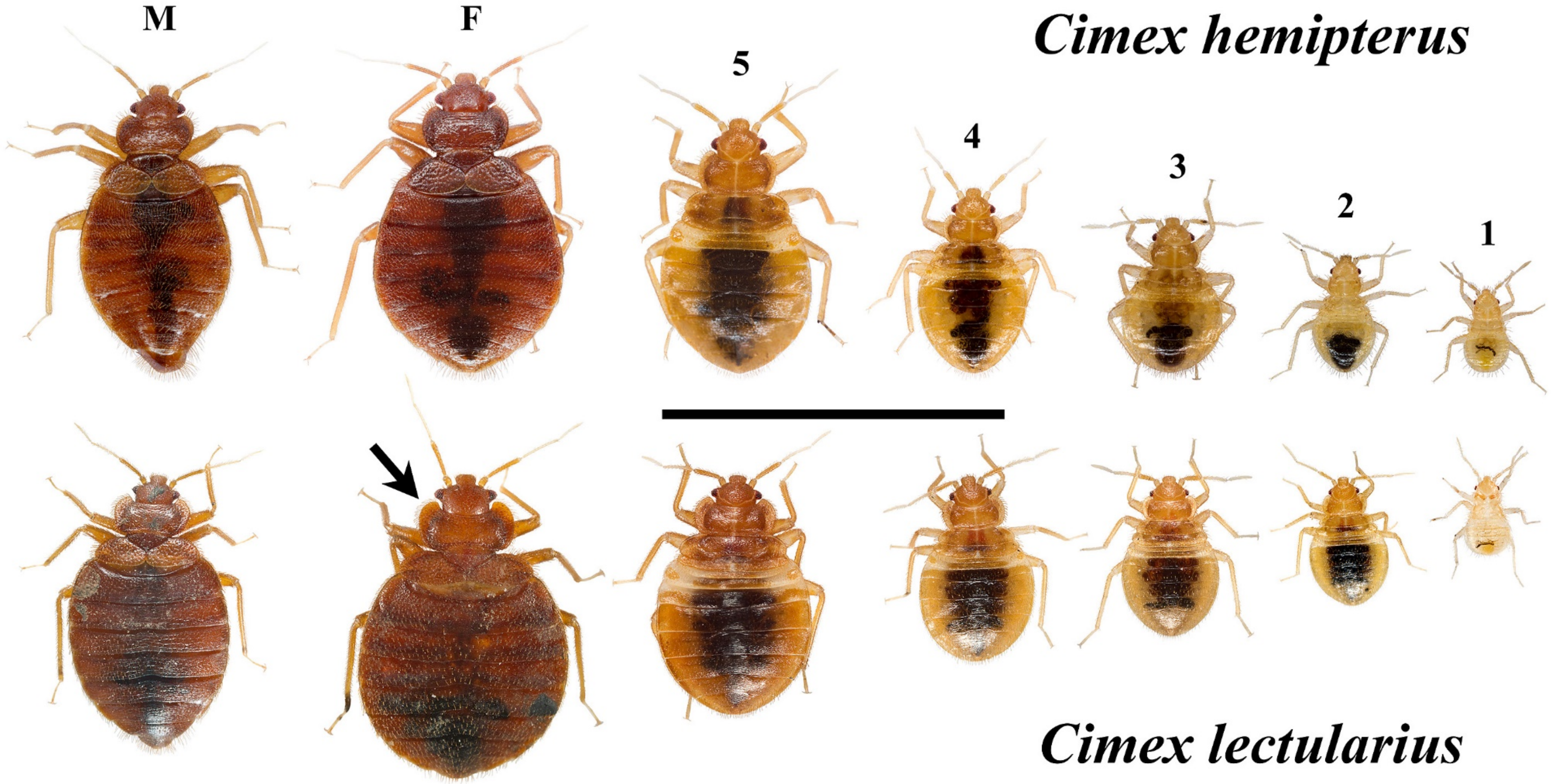
M
F
5
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1
Cimex hemipterus
Cimex lectularius