

THE RESURGENCE OF BED BUGS, *CIMEX* SPP. (HEMIPTERA: CIMICIDAE) IN AUSTRALIA

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Abstract From 2001 to 2004, Australia experienced a resurgence in bed bug infestations involving both the common (*Cimex lectularius*) and Tropical (*Cimex hemipterus*) species. It was found that all Australian mainland states had experienced an exponential rise in bed bug infestations since 2001, with an overall national increase of 4.5%. A conservative estimate of the economic impact of the resurgence was \$AUS100 million. To combat the resurgence, a four point strategy was implemented. The first strategy was to better define the degree of the resurgence through a survey of professional pest managers. The second strategy was the defining of best practice in bed bug management, which led to the development in 2005 of a Code of Practice for the Control of Bed Bug infestations in Australia (CoP) (www.bedbug.org.au). The aims of the CoP were to promote best practice in the eradication of active bed bug infestations and the management of potential infestations. Education of stakeholders affected by bed bugs on best practice management as defined by the CoP was the third strategy and encompassed the production of industry publications and lectures. Research, and investigations have begun in relation to both non-chemical and chemical means of control.

Key Words *Cimex lectularius* survey, best practice, education, management.

INTRODUCTION

Australia, like many other parts of the world, has experienced a major resurgence in bed bug infestations. For example, from 2001 to 2004, our Department recorded a 250% increase in bed bug samples, while one pest control company noted a 700% rise in treatments (Doggett et al., 2004e). Around this time, the Tropical bed bug, *Cimex hemipterus* (F.) also became established, meaning that the entire country had become receptive to potential bed bug infestations (Doggett et al., 2003). In response to the resurgence, a strategy was implemented that encompassed four key areas: *Recognition*, *Development of 'Best Practice'*, *Education* and *Research*.

In *Recognition*, the aim was to more accurately define the degree of the resurgence and the ultimate economic impact upon the nation. The *'Development of Best Practice'* led to the introduction of an Australian Code of Practice for the Control of Bed Bug infestations (Doggett, 2005b, 2006a, 2007a, 2007d). The aims of the Code being to promote 'best practice' in the eradication of active bed bug infestations and the management of potential infestations. *Education* focused on training the various stakeholders impacted by bed bugs on best practice in the management of bed bugs. *Research* has been undertaken in order to investigate more effective means of bed bug control. Each of these strategies will be discussed in turn, preceded by an overview of the history of bed bugs and their control in Australia.

History of Bed Bugs in Australia

The early global expansion of bed bugs has been linked to the age of the sailing vessel and it is thought that this was the means by which bed bugs were introduced into Australia. Thus, it is probable that the bugs came with the first European settlers in 1788 via sailing ships (Woodward et al., 1970). This suspicion appears confirmed by the writings of early Australian naval explorers such as Matthew Flinders who was the first person to circumnavigate and map the nation. He wrote of his trials and tribulations with bed bugs upon his ship, the *Cumberland*, in 1803 (quoted by Flannery, 2000): "...for bugs...[this schooner] rises superior to them all...but in spite of boiling water and daily destruction amongst them, the bugs still keep their

ground...not withstanding which I have at least one hundred lumps on my body and arms; and before this vile bug-like smell will leave me, must, I believe, as well as my clothes, undergo a good boiling in the large kettle." Generally however, there appears to be few historical accounts of people's personal experiences with bed bugs in Australia. The probable reason for this was best summed up in the seminal Australian entomological text of the early 20th century, *The Insects of Australia and New Zealand* (Tillyard, 1926): "[the Cimicidae is] represented in [Australia] by the detestable and all too common...bed bug...which is too well known to need description here."

Thus as bed bugs were such an everyday part of life, Tillyard considered that there was no need to include details of such a common insect pest! Perhaps the most vivid account of the nightmare of bed bugs during the early post-war (WWII) years in Australia before the widespread use of DDT, was provided by Ruth Park (1948), writing of the experiences of Irish immigrants in slum areas of Sydney: "As the darkness grew deeper, the bugs came out of their cracks in the walls, from under the paper and out of the cavities in the old bedsteads where they hung by day in grape-like clusters. They were thin and flat and starved but before dawn they would return to their foul hiding places round and glistening and bloated with blood. Captain Phillip brought them in the rotten timbers of this first fleet and ever since they have remained in the old tenement houses of Sydney, ferocious, ineradicable, the haunters of the tormented sleep of the poor." Despite being a fictional work, it was likely that Ruth Park's account was based on actual personal experiences having lived in the location where her novel was based.

The decline of bed bugs in Australia during the 1950's following the introduction of DDT was not documented. During this period, anecdotal evidence from older pest managers suggested that infestations were often associated with socially disadvantaged groups. Correspondence kept by the Department of Medical Entomology at the School of Public Health and Tropical Medicine at the University of Sydney (this was national Medical Entomology reference laboratory at the time and the forerunner to the Department of Medical Entomology at Westmead Hospital), from 1949 to 1983, revealed only two references to bed bugs in Australia. The first was in 1967 and involved *Cimex lectularius* L. (the specimens were retained and the identification was re-confirmed by the senior author SLD) in a home in an affluent area of Sydney, the other was from 1974 and was associated with staff of a major international airline who presumably acquired them from overseas. It can be assumed that bed bug infestations during this period were rare.

The first published mention of a resurgence of bed bugs in Australia was in a New Scientist article (Coghlan, 2002), with the comment, "From New York to Sydney...bed bugs are making a comeback." The initial source for this report has not been fully established, although Coghlan mentioned to the senior author (SLD) that it was attributed to a Medical Entomologist from the University of Cambridge. Either way, the facts were indeed correct. Some two years prior to this report, an infestation in England was linked to luggage coming from Australia (Paul and Bates, 2000), which is probably the earliest documented case linked to Australia from the era of the modern resurgence.

The first scientifically documented evidence in Australia was provided by the authors and colleagues (Doggett et al., 2004e). In this report it was stated that the Department of Medical Entomology pathology service at Westmead Hospital, had received an increase in the number of bed bug samples of almost 250%. This was from the beginning of January 2001 to January 2004, compared with the previous four years. The Department also had a notable increase in the number of bed bug related emails. Over the three-year period from 1998 to 2000, 16 bed bug enquiries were received, while from the start of 2001 to January 2004 there were 138 (Doggett et al., 2004e). The Department had moved from the University of Sydney to Westmead Hospital in 1988 and, in that year, a single bed bug sample was received. No further were received until three samples were submitted in 1994. In 1995 there were two, 1997 - four, 1998 - five, but none further until 2001. Perhaps in hindsight, the samples from the mid 1990s were the first indication of the resurgence in Australia.

Other organisations reported comparable increases. The Australian Quarantine and Inspection Service (AQIS) saw a dramatic increase in the number of bed bug interceptions from 1999 onwards. Likewise, similar reports were made by other government bodies, including the South Eastern Sydney Public Health Unit in New South Wales and the Pesticide Safety Branch, Western Australia Department of Health. Further, the pest control industry was becoming more involved, with one pest manager reporting some 50 treatments

of bed bugs from late 2000 compared with some five in the preceding 25 years, while another saw more than a 700% increase in the number of treatments (Doggett et al., 2004e).

In 2003, the first report of the Tropical bed bug, *C. hemipterus*, in Australia was published (Doggett et al., 2003). This species was originally identified from a sample collected in a café in coastal Queensland in 1998. Ironically, the title of the paper was “Has the Tropical Bed Bug...invaded Australia?” The answer now is a categorical ‘Yes’! It appears that the New South Wales / Queensland (QLD) border is the approximate delineation of both species; both are sympatric in the Gold Coast in south eastern QLD. To the south of this is the realm of the Common bed bug and the Tropical to the north (Figure 1). When this latter species was actually introduced into the country is not known. Since the publication of the 2003 paper, older museum specimens of *C. hemipterus* have been uncovered, with preserved samples from Katherine (Northern Territory) in 1991, and Darwin (Northern Territory), in 1994, and both specimens having been collected from backpacking lodges. Thus it is probable that the species was established for some years before being formally recognised.

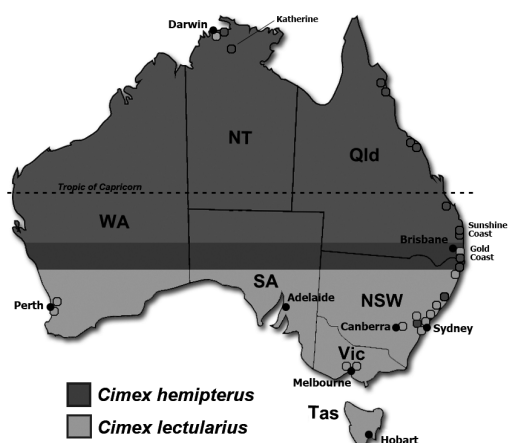


Figure 1. Estimated Australian distribution of the Tropical bed bug, *Cimex hemipterus*, and the common bed bug, *Cimex lectularius*, based on identified specimens (circles). Most records are based on multiple samples, however for the three samples depicted outside their respective normal ranges, these were from single infestations. The black circles depict the location of capital cities. Locations mentioned in the text are also included.

Following an increase in anecdotal accounts of bed bug infestations, the City of Sydney Council initiated a survey of short-stay accommodation. The survey involved a questionnaire, rather than site inspections, and so there may have been an under-reporting of the true incidence. However, 79% of the short stay lodges in the survey reported that their facility had in recent times been impacted by bed bugs (Ryan et al., 2005). The manager of one of these operations stated to the senior author that up to 35% of their beds were infested during the 2004 summer. Unfortunately, this is not a unique case; several others in the accommodation industry have reported similar rates to the author from both within and outside of New South Wales. Another backpacking lodge from the north of the country (not identified due to confidentiality) has stated to the senior author in 2006 that every bed in their facility has had bed bugs on at least one occasion.

During the early years of the resurgence, a number of pest managers noted that many insecticide products, particularly the synthetic pyrethroids (SP), gave poor control and multiple retreatments were required. This suggested that the current crop of bed bugs had some degree of resistance. Further evidence supporting the suggestion of resistance came in 2004 when bed bugs were collected walking over permethrin dust. A colony from these particular bugs has been established at the Department of Medical Entomology, although the degree of resistance has yet to be quantified.

The History of Bed Bug Control in Australia

There are few historical accounts of bed bugs in Australia, likewise methods of control were poorly reported. Froggatt in 1919 suggested the use of hydrocyanic acid gas, the dose per an area of 1,000 cubic feet being “1 lb cyanide, 1 lb sulphuric acid and 48 oz water” (Froggatt, 1919). Undoubtedly such a highly toxic cocktail would have been very effective at killing bed bugs, but would have been equally effective at removing humans from the gene pool as well.

Perhaps the reason that there are so few records of bed bug control post WWII was due to the great effectiveness of the organochlorides (OC). With such highly efficacious insecticides it appears that control was relatively simple. In 1967, David Lee the Chief Medical Entomologist at the School of Tropical Medicine and Public Health, University of Sydney, gave the following advice on bed bug control in a personal correspondence (Lee, 1967): *“If the house in question is sufficiently enclosed for a smoke fumigation with Lindane this is the simplest type of treatment. As it is more likely that the house is not suitably designed for fumigation residual strength DDT would be the insecticide of choice. No doubt you will have to use what is immediately available and probably this means a water wettable powder, broken down to between 5% and 10% active DDT. In some countries there is resistance to DDT but I would not expect this in your case — keep in mind, if the treatment happens to fail then switch to Lindane. Complete interior treatment would usually be less effective than a discriminating treatment of areas of infestation. The bed bugs hide in crevices during the day and these hiding places are close to the site of nocturnal feeding as possible. If the bed has crevices these must be treated, including mattress buttons if any. Adjacent wall areas require much more attention than those of the opposite side of the room. If the floor provides possible diurnal resting places these must be treated. Spray treatments cannot usually be made to penetrate fully into resting places so one relies on treating surfaces over which the bugs have to walk to obtain their blood meal. Average length of egg stage is about 10 days...so a further treatment in 2-3 weeks may be desirable. If the infestation is of long duration faecal spotting will indicate concentrations of bugs, if not — success of the operation is largely dependent on the care with which resting areas are detected and treated.”*

The above is one of the few records of bed bug control from the era of OC use in Australia. Despite the availability of a powerful arsenal of insecticides, a great attention to detail is still recommended; a good lesson for modern day pest managers who now have a much depleted insecticide arsenal.

As the OCs becoming less acceptable by society for pest control, the carbamates, organophosphates (OP) and SPs took their place. The main actives available during this period were propoxur, dichlorvos, fenthion, diazinon and permethrin, and these were present in a variety of formulations (Hadlington and Gerozisis, 1985). Since that time, for various reasons, many of these products are either no longer registered for use or not routinely employed for bed bug control in Australia. These reasons include: health concerns (e.g. dichlorvos), odour issues (e.g. diazinon), and the active not being re-registered (e.g. propoxur dusts and liquid concentrates). As of 2008, the vast majority (~90%) of products registered for bed bug control contain SPs as the main active, with a few carbamates and OPs available (Doggett, 2007d). The actives and their respective formulations are listed in Table 1. Note that there are no insect growth regulators (IGRs), nor any of the silicate compounds, currently registered for bed bug control in Australia.

Table 1. Insecticides registered for bed bug control in Australia as of January 2008.

Active Ingredient	Formulation	Mode of Action Group*
Bendiocarb	DP, WP	1A
Betacyfluthrin	SC	3A
Cyfluthrin	AC, WP	3A
Deltamethrin	SC	3A
Diazinon	EC	1B
Permethrin	DP, EC, WP	3A
Pirimiphos-Methyl	EC	1B
Various aerosols containing synergised pyrethroids, some with propoxur.	Aerosol	Mostly 3A

AC= Aqueous Concentrate, DP=Dustable Powder, EC= Emulsifiable Concentrate, SC=Suspension Concentrate, WP=Wettable Powder. *see the Insecticide Resistance Action Committee web site www.irac-online.org for details on the various modes of action.

Over the last two years, there has been a number of international reports of insecticide resistance to the SPs, the carbamates and the OPs (Boase et al., 2006; Karunaratne et al., 2007; Romero et al., 2007). Thus, all of the insecticides registered here belong to those groups where resistance has been reported, and it was perhaps not surprising that large numbers of treatment failures were being reported. This meant that attitudes towards bed bug control in Australia had to change and prompted the development of an industry code of practice for bed bug control, which is discussed later.

2006 Survey of Australian Professional Pest Managers

Following on from the 2004 publication that first reported on the resurgence in Australia (Doggett et al., 2004e), anecdotal reports suggested that bed bug infestations were still continuing to escalate. These latter reports, and the fact that the 2004 paper was based on a relatively limited data set, suggested the need for a more detailed investigation. As a result, a survey of Australian pest managers was undertaken in 2006, with the principle aim being to more accurately document the extent of the bed bug resurgence. With this information, along with detailed costs of bed bug treatments, it was then possible to estimate the ultimate economic impact of bed bugs upon the nation. Another important aim was to record pest manager procedures and behaviours in relation to bed bug management. The survey coincided with the release of the 'Code of Practice for the Control of Bed Bug Infestations in Australia' (Doggett, 2006d) and the survey was used to help promote awareness of this code amongst the pest management industry. The survey was undertaken in July 2006 and thus the data do not represent the situation for the entire calendar year.

The questions in the survey included: List the number of bed bug jobs by year since 2000 and total pre-2000; List the number of jobs/property type; What is average number of treatments you need to eliminate an infestation; What is the average time spent per treatment?; Which insecticides do you find most effective?; Which insecticides have you found ineffective?; What control methods do you use?; Do you always reinspect the site after each treatment?; Have you read the Draft Bed Bug Code of Practice (www.bedbug.org.au)?; Did you find it useful for your treatment methods?; Would you be interested in attending a full day course on bed bug control?

The survey was produced in paper format for inclusion in the conference satchel of the annual national pest management meeting in 2006 and as a PDF for electronic distribution. Electronic copies of the survey were sent via the distribution lists held by The Australian Environmental and Pest Managers Association (AEPMA, which is the national pest management association), the main insurance body for pest managers (Rapid Solution) and major insecticide supply companies (Garrards and Agserv).

Survey Results. There were 121 respondents to the survey. The numbers of respondents by state were: 50 from New South Wales (NSW), 42 from Queensland (QLD), 9 from Victoria (Vic), 8 from Western Australia (WA), 6 from South Australia (SA), 4 from the Australian Capital Territory (ACT) and 2 from the Northern Territory (NT). There were no respondents from Tasmania (Tas). A total of 571 bed bug jobs were reported before the year 2000 and 8,708 from Jan 2000 to July 2006.

Table 2 lists the number of bed bug jobs by year since 2000 and the total pre-2000. All states reported a dramatic rise in bed bug numbers, with an average across Australia of 4,500% since 1999 (Figure 2). Each state followed a similar trend (Figures 3-9) and demonstrated exponential growth in bed bug infestations over recent years. The percentage increases by state were: ACT (495% since the year 2000), NSW (8,434% since 2000), NT (650% since 2004). QLD (2,622% since 1999), SA (6,450% since 2000), WA (5,780% since 2000) and Vic (15,825% since 2000). Table 3 lists the property types treated. The most commonly reported properties were 1-3 star motels (24.7%), followed by backpacker lodges (21.9%). Table 4 lists the reported average number of treatments to eradicate bed bug infestations. Overall, the reported average number of treatments required was 2 treatments. Table 5 details average number of treatments needed to eliminate infestations. The overall average time spend on a bed bug treatment was 2.1 hours. Table 6 lists the insecticides that are considered most effective for bed bug control. The most effective insecticides listed were the SPs (44.7%), the carbamates (38.3%), the OPs (9.9%) and the IGRs (4.3%). Fifteen (16%) reported use of insecticides currently not registered (e.g. IGRs). Table 7 lists the insecticides that are considered not to be effective for bed bug control. The least effective reported were the SPs (94.1%), the carbamates (3.9%) and the OPs (3.9%).

Of the main control methodologies, 29 (26% of respondents) reported using vacuuming, 25 (23%) reported using steam, and all employed insecticides. Other control methodologies reported included: physical removal (2 respondents), black plastic (2), heat via sunlight (1), stiff bristle broom (1), fogging (1), sealing gaps (1), heat, e.g. paint stripper heat guns (2), squashing them (1) and freezing (1). The majority (79%) of pest managers reported undertaking a reinspection after treatment. Most (69%) pest managers reported reading the Draft Bed Bug Code of Practice and a high percentage (95%) found it of assistance. Additionally, the majority (89%) of pest managers expressed an interest in further education in bed bug control by attending a full day course.

Table 2. The number of bed bug jobs reported per year.

<2000	2000	2001	2002	2003	2004	2005	2006*	Total
571	158	191	354	1004	2112	2464	2425	9279

*Data not complete for 2006 calendar year

Table 3. Property types treated.

Property Type	No.	%	Property Type	No.	%
1-3 Star Motels	2069	24.7	Charter Boats	82	1.0
Backpacker Lodges	1832	21.9	Campervans/Motor homes	31	0.4
Homes	1062	12.7	Brothels	25	0.3
4 Star Motels	874	10.5	Ships	12	0.2
Rented Properties	724	8.7	Boarding School	6	0.1
Trains	489	5.8	B&Bs	2	0.0
5 Star Motels	445	5.3	Dormitories	2	0.0
Resorts	462	5.5	Farm Stay	2	0.0
Staff Accommodation	153	1.8	Hospitals	2	0.0
Caravan/Cabin Parks	86	1.0	Total	8360	100.0

Table 4. The Average number of treatments needed to eliminate infestations.

No. Treatments	1	1-2	2	2-3	2-4	3	3-4	4	1-5
No. responses	16	14	38	12	3	13	2	2	1
%	15.8	13.9	37.6	11.9	3.0	12.9	2.0	2.0	1.0

Table 5. The average time spent per bed bug treatment.

Time (hr)	No. responses	%	Time (hr)	No. responses	%
0.5	3	2.8	2.5	12	11.3
0.75	4	3.8	3	7	6.6
1	18	17	3.25	1	0.9
1.25	6	5.7	4	9	8.9
1.5	16	15.1	5	2	2
1.75	3	2.8	6	2	2
2	22	20.8	8	1	1

Table 6. Effective insecticides for bed bug control.

Trade name	Active	No.	%
Blattanex	Propoxur, tetramethrin, PBO	27	29.7
Ficam	Bendiocarb	23	25.3
Permethrin	Permethrin	13	14.3
Cislin	Deltamethrin	11	12.1
Actellic	Primiphos methyl	10	11.1
Betacyfluthrin	Betacyfluthrin	10	11
Crackdown	Deltamethrin, tetramethin	9	9.9
Unspecified brand	Deltamethrin	7	7.7
	Unspecified synthetic pyrethroids	6	6.6
	Unspecified carbamates	4	4.4
Unspecified brand	Bifenthrin*	3	3.3
Unspecified brand	Diazinon	3	3.3
Sumilarv*	Pyriproxyfen	3	3.3
Bestox*	Alpha-cypermethrin	2	2.2
	Unspecified IGRs*	2	2.2
Pounce*	Permethrin	2	2.2
Any insecticide	Unspecified	2	2.2
Baytex*	Fenthion	1	1.1
Dursban*	Chlorpyrifos	1	1.1
Triflumuron*	Triflumuron	1	1.1
Botanical	Pyrethrin	1	1.1

*Unregistered products, PBO = Piperonyl butoxide

Table 7. Insecticides found ineffective for bed bug control.

Trade name	Active	No.	%
Unspecified brand	Deltamethrin	17	37.0
	Unspecified synthetic pyrethroids	11	23.9
Unspecified brand	Permethrin	8	17.4
Unspecified brand	Bifenthrin	3	6.5
Crackdown	Deltamethrin, tetramethin	3	6.5
Responsar	Betacyfluthrin	2	4.3
Tempo	Betacyfluthrin	2	4.3
Blattanex	Propoxur, tetramethrin, PBO	1	2.2
	Unspecified carbamates	1	2.2
Insectigas*	Dichlorvos	1	2.2
Pestigas*	Pyrethrins, PBO	1	2.2
Preclude*	Pyrethrins, PBO	1	2.2

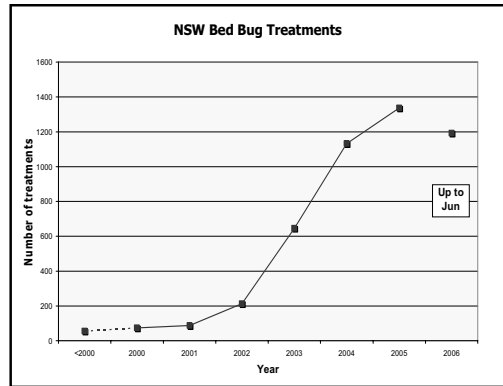
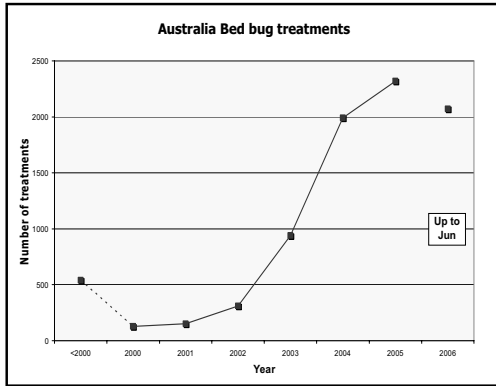
*Unregistered products. PBO = Piperonyl butoxide

Survey Discussion. The total of 121 respondents sampled represented only a small part of the pest management industry; the number of registered pest managers is variously estimated to be somewhere around 4-6,000 within Australia. Thus, the overall number of bed bug infestations reported by the survey represents a gross underestimate of the true figure. Even if the survey only captured 10% of those jobs undertaken by pest managers, then the number of infestations since the year 2000 approximates 100,000. These figures also do not include complete data from the backpacking industry, who often undertake some form of control themselves, and as this industry has been especially impacted by bed bugs, it is probable that the true number of treatments since the beginning of the resurgence is considerably more than double this figure. As the backpacking industry is under represented, the percentage of treatments as listed by property type for this group is thus not an accurate representation of the true situation.

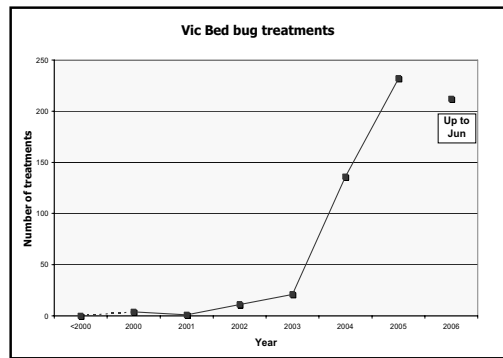
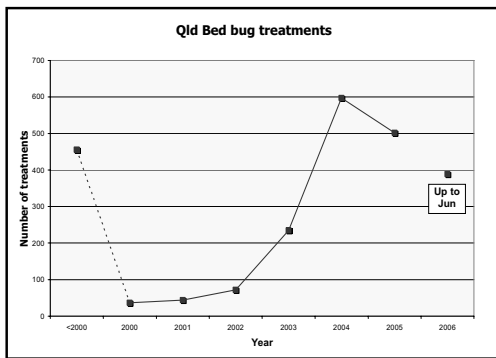
Another aspect that may have led to underreporting is that many pest managers equated 'Number of Bed Bug Jobs' in the survey with invoices per facility rather than actual jobs. For example with one company, one invoice equalled 48 separately treated rooms within a staff accommodation block, and in another case, one invoice represented treatments in 39 rooms within a motel complex.

On initial examination, there appears to be some irregularities with the state data. For example, the high number of treatments pre-2000 in QLD was largely due to one pest manager undertaking 370 treatments in one staff accommodation facility in 1999. The QLD data also suggest a drop in treatments during 2005; however, one Pest Manager who had undertaken 100 bed bug jobs in 2004 stopped due to the development of severe conjunctivitis resulting from the high quantities of insecticides required to eradicate an infestation. Another pest manager undertook training of housekeeping staff during 2004 and many of these clients stopped employing him for control (although some of these were later to suffer recurrent bed bug infestations). A third pest manager, who undertook over 100 jobs in 2004, subsequently moved out of the state. Thus, the apparent decline is artificial and there were relatively few survey respondents from some of the most severely bed bug impacted regions, such as the tropical far north, and the Sunshine and Gold Coasts in the south east corner of QLD.

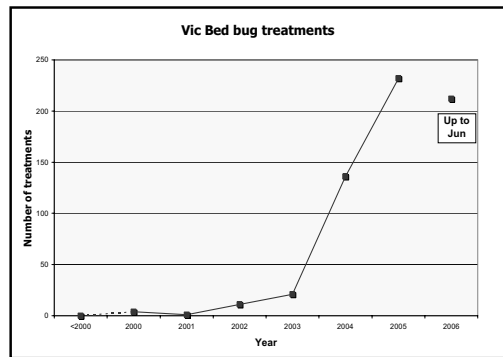
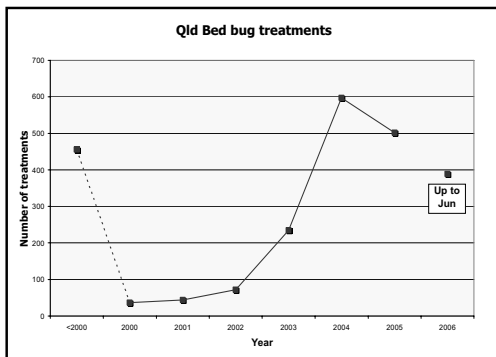
The graph of Figure 2, that shows the national figures for bed bug treatments since 2000 in Australia, does hide some important information in terms of when different groups started to be impacted by bed bugs. From personal experience of the authors and the anecdotes of the accommodation industry and pest managers, it appeared that backpacking industry was the first major group afflicted by the bed bug resurgence. In hindsight, this began in the mid to late 1990s. During the early 2000s, infestations started to appear in middle- to up-market motels, and by around 2002/3 there was an increasing number reported from private residences. Since that time, bed bug infestations have spread into the wider community as noted by the wide range of residential types reported in the survey. Since the 2006 survey, the authors have been involved in an infestation in a cinema complex and in late 2007, a major outbreak in a children's hospital ward. In this instance, 18 rooms were found infested, yet only one patient bed was found with bed bugs; the infestations were in lounge chairs (where parents often sleep overnight) and bed side furniture. Perhaps the most disturbing trend since 2006 is the growing incidence of bed bugs amongst the socially disadvantaged. These infestations can be massive, involving thousands to tens of thousands, to even hundreds of thousands of bugs. The reasons for the infestations becoming out of control can be due to the fact that the tenant has impaired cognitive capabilities and may not be aware of the infestation, or they may not have the economic capability to pay for control.



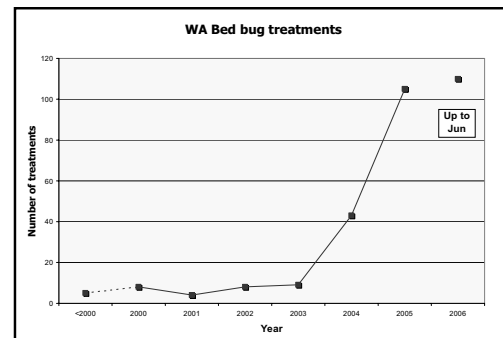
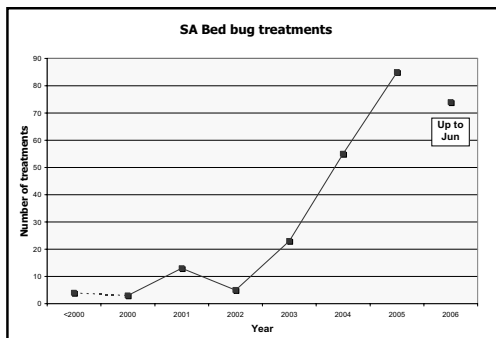
Figures 2 and 3. Annual bed bug infestation data as recorded by the 2006 Bed Bug Survey for pre and post the year 2000. Data combined for Australia (left graph) and New South Wales (NSW).



Figures 4 and 5. Survey results for Queensland (Qld) and Victoria (Vic).



Figures 6 and 7. Survey results for South Australia (SA) and Western Australia (WA).



Figures 8 and 9. Survey results for Northern Territory (NT) and the Australian Capital Territory (ACT).

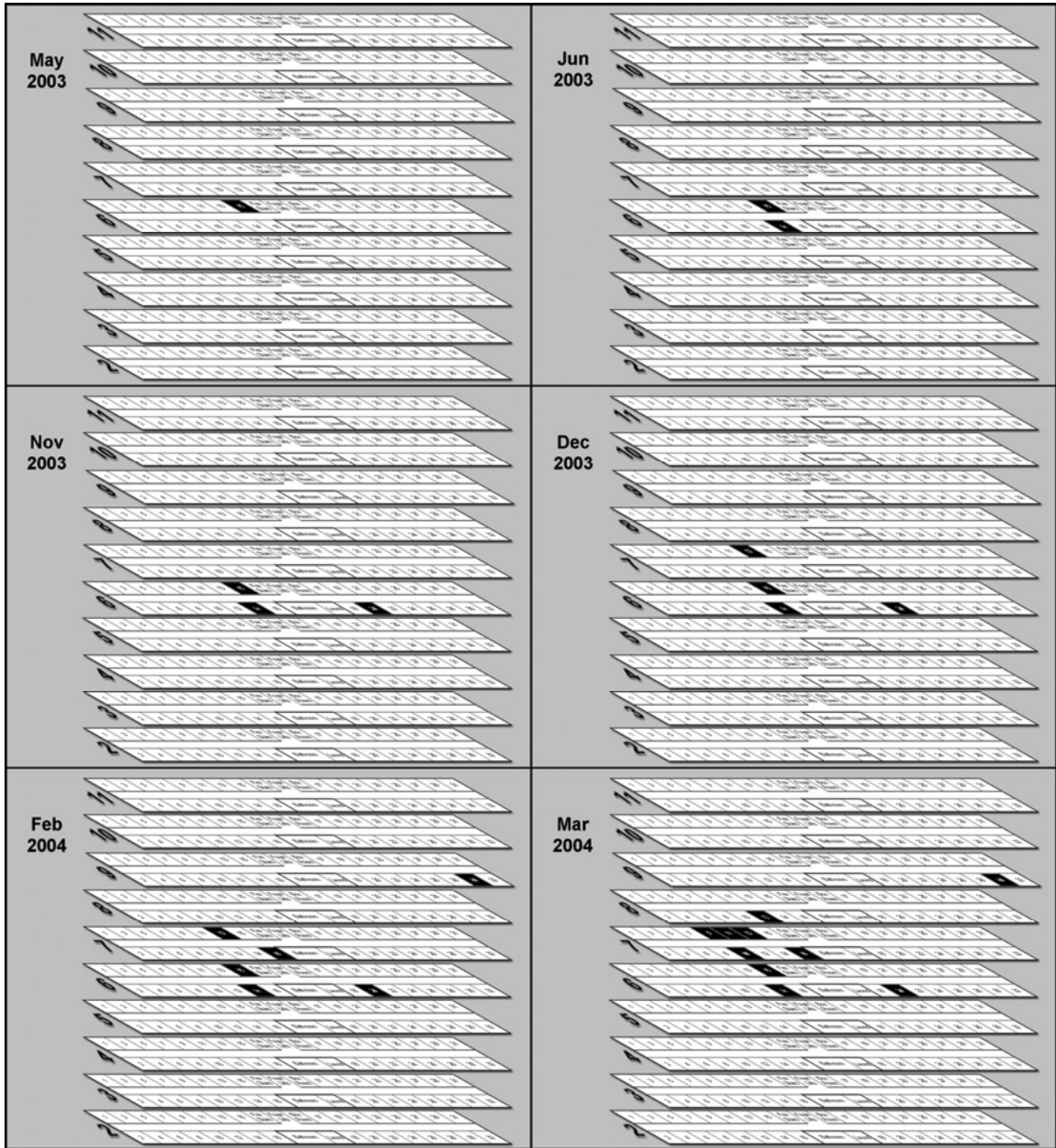


Figure 10a. Tracking the spread of bed bug infestations within a staff accommodation complex (10 floors of 32 rooms/floor) of a major Sydney teaching hospital. The infestations reported up until June 2005 are based on incident reports. These figures cover the incident reports from May 2003 to March 2004.

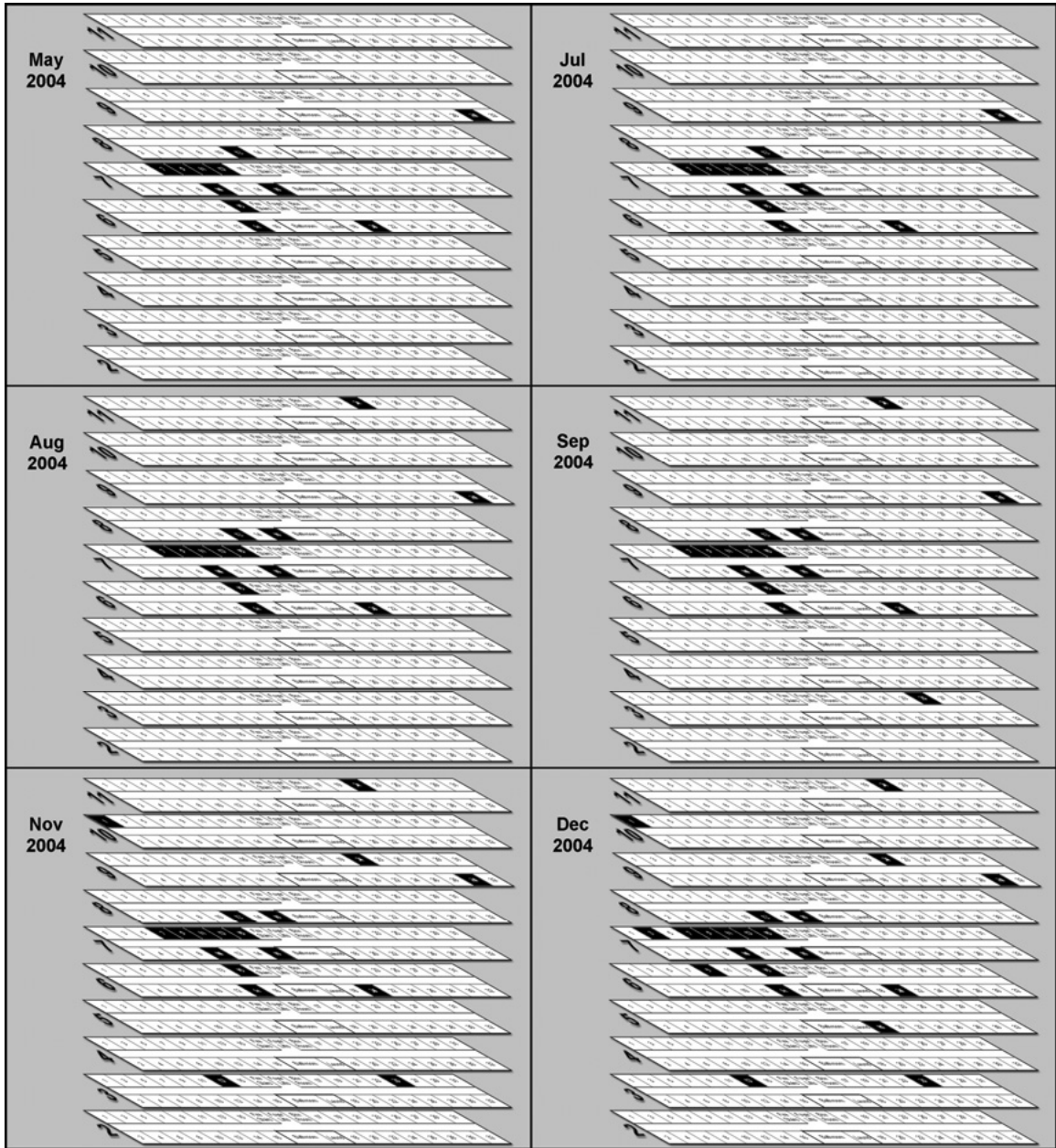


Figure 10b. Tracking the spread of bed bug infestations in a staff accommodation complex of a major Sydney teaching hospital. These figures cover the incident reports from May to December 2004.

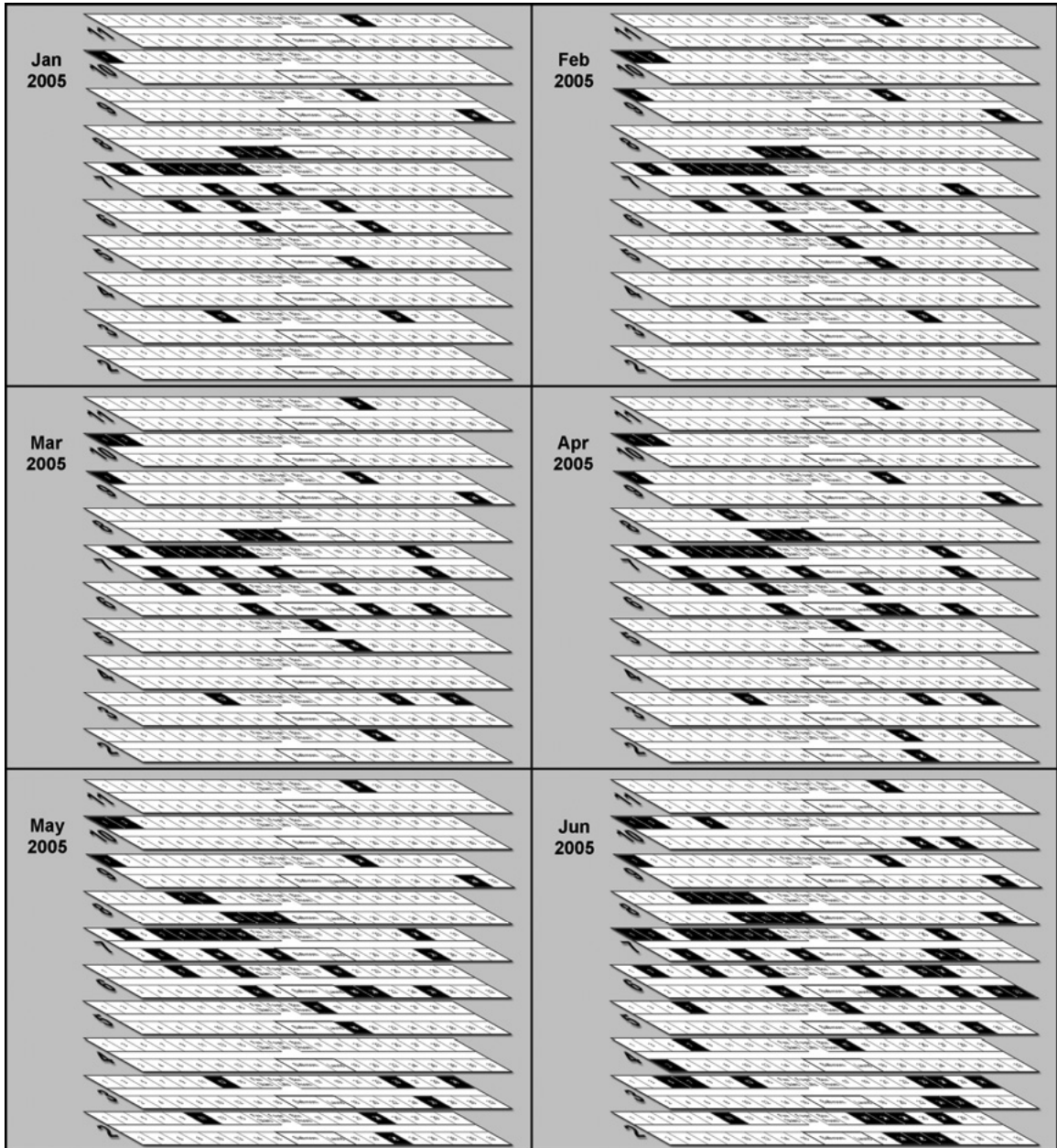


Figure 10c. Tracking the spread of bed bug infestations in a staff accommodation complex of a major Sydney teaching hospital. These figures cover the incident reports from January 2005 to May 2005. By May 2005, 10% of the rooms were infested, which led to all rooms being inspected by a bed bug experienced pest manager. A total of 20% of the rooms (June 2005 in the figure) had evidence of bed bugs.

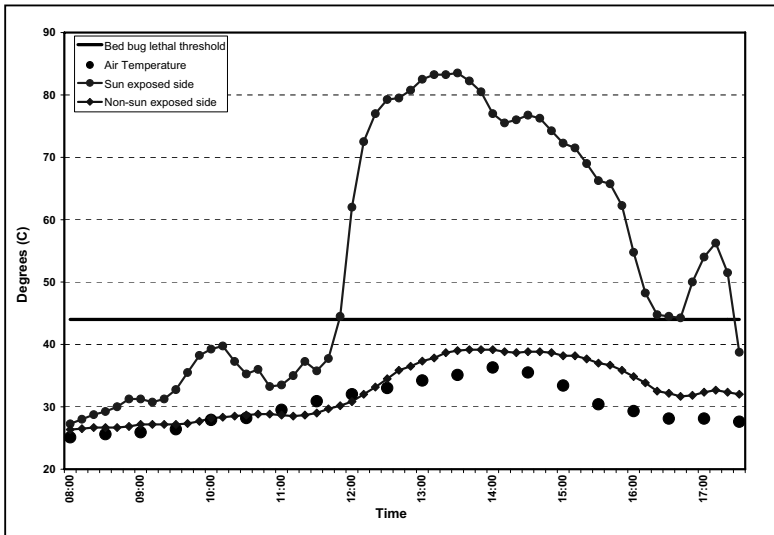


Figure 11. Results of the ‘Black Plastic’ investigations with the thin mattress.

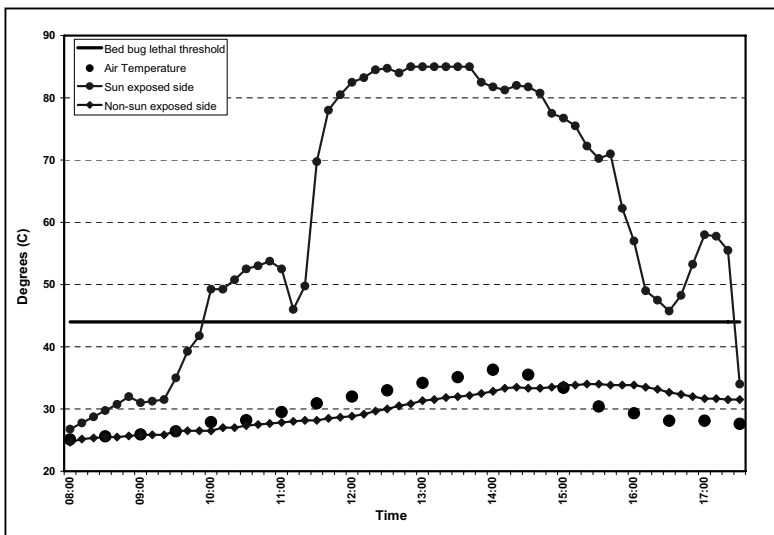


Figure 12. Results of the ‘Black Plastic’ investigations with the thick mattress.

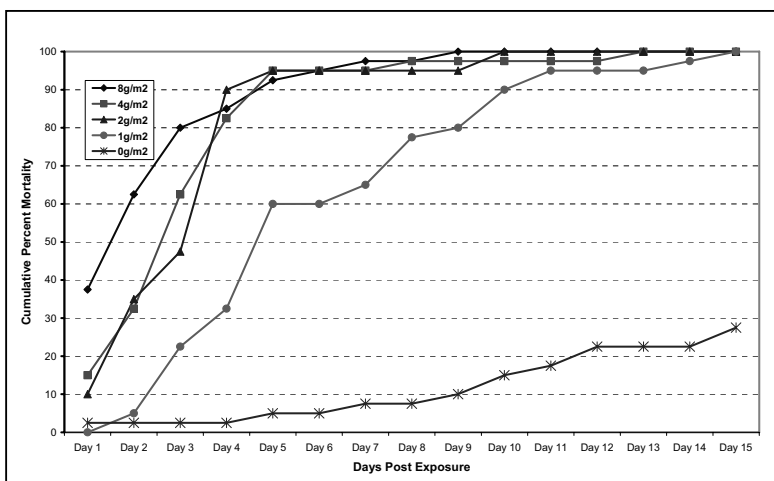


Figure 13. Cumulative mortality of the adult common bed bug, *Cimex lectularius*, exposed to varying doses of diatomaceous earth.

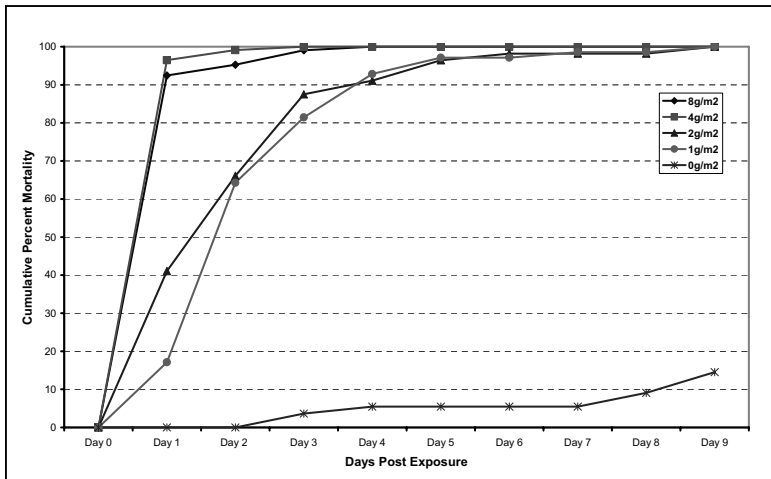


Figure 14. Cumulative mortality of first instars of the common bed bug, *Cimex lectularius*, exposed to varying doses of diatomaceous earth.

The inevitable outcome of such infestations is that the bugs spread widely within multistorey dwellings. In one case in Sydney, the bed bugs spread four floors away from the prime infestation. In response to this trend, a new section on dealing with bed bugs in such circumstances was included in the second edition of the Australian bed bug code of practice. It was not surprising that all respondents reported using insecticides to manage bed bugs. However, the high rate of vacuum (26%) and steam (23%) usage was not expected, as from personal experience of the authors working with pest managers, these control tools are rarely, if ever, utilised. Survey respondents were requested to include their name and contact details. As the data were identifiable, the possibility cannot be excluded that some pest managers may have stated on the form what they perceived to be the correct methods of control rather than their actual methods of control.

It was perhaps to be expected that the insecticides considered most effective for bed bug control were the SPs, since around 90% of the insecticides currently registered in Australia against bed bugs have an SP as the active. Generally, the SPs are the main insecticide group of choice in Australia as they are highly effective against most arthropod pests and have a very low mammalian toxicity. Yet 94.1% of respondents reported that SPs were ineffective for bed bug control, which is another good indication of the high degree of insecticide resistance in Australia.

The high number of pest managers reporting the use of unregistered insecticides is perhaps a reflection of the poor performance of many of the currently available products, possibly due to insecticide resistance but also to poor application methodology. Interestingly, very few of the more experienced pest managers (namely those who recorded >100 jobs) reported product failure; perhaps this is an indication of the acquired wisdom in relation to bed bug control and the knowledge that diligence and perseverance are the essential keys to modern bed bug eradication.

It is a concern that 21% of the respondents reported no follow up inspection. The insecticides used today are all non-ovicidal. The eggs take some days to hatch and the infested areas need to be retreated as most products have a poor residual effect (probably due to resistance), which may not be lethal to the emerging nymphs. Attempts to redress this situation and to educate pest managers that a reinspection must always be undertaken are currently underway.

For those pest managers who read the 'Code of Practice', 95% found the document beneficial. This endorsement should encourage all other Australian pest managers to consult the Code, even if they have experience in bed bug management.

The Economic Impact of Bed Bugs

The actual costs associated with bed bug infestations to date have not been recorded. The lack of such information means that the overall economic impact to the Australian community can not be calculated. This information is needed to prioritize much needed funding for research into better bed bug management strategies.

In order to calculate the economic burden due to bed bugs, the Department of Medical Entomology and Eagle Pest Control (a Sydney based firm) collaborated with two accommodation facilities that have experienced recurrent bed bug infestations (data unpublished). One facility was a staff accommodation block attached to a tertiary health care facility. Between 2003 and 2005, bed bugs became a serious issue and rapidly spread throughout the building. Figures 10a, b and c, show the spread of the infestation, which was recorded via staff incidence reports. The first infestation was identified and treated (albeit poorly) in May 2003 and, by May 2005, 10% of the rooms were infested, which led to all rooms being inspected by a bed bug experienced Pest Manager. The final survey (July 2005 in Figure 10c) revealed that a total of almost 20% of the rooms had evidence of bed bugs (68 rooms infested). Costs in this instance included: replacement of bedding and linen (>A\$7,220), pest control (approx. A\$32,000), control equipment (>A\$1,000) and intellectual support (>A\$2,000). The total of around A\$42,000 equates to A\$617/room, although many costs were not included such as the medical expenses for treating afflicted staff, loss of productivity with such staff, and various miscellaneous costs. Usually the loss of income through room closure represents a major economic loss to accommodation providers; however, in this situation the staff rent their rooms on a long term basis and thus there was no associated loss of income.

The second facility was a three star Sydney inner city motel. This particular motel had 39 rooms infested out of a total of 110 rooms (i.e. 35.5% of rooms). Costs included: loss of income with room closures during treatment (A\$36,312.00), pest control (A\$14,870.90), linen replacement (A\$585.00), refurbishment (A\$3,900.00), refunds (A\$3,471.00) and miscellaneous (A\$390.00). The total was A\$59,528.90 or A\$1,526.38 per room. This amount did not include the replacement of mattresses and furnishings, nor the loss of patronage, and thus the real costs are likely to be substantially higher.

It is unlikely that these costs would be representative across the entire accommodation industry or for the homeowner. As noted previously, backpacker lodges regularly undertake the control themselves and often do not close rooms for treatments, and thus the costs would be considerably less. In comparison, a five star motel loses more money when a room is closed, and it will keep rooms closed for longer as there is a greater fear of litigation, and so costs are much greater. For the homeowner, mattresses and beds are often discarded, and so overall control costs are usually even relatively greater. Thus, to accurately determine the overall economic burden of bed bugs to the Australian community is virtually impossible. However, if the average cost per infestation is around A\$1,000 and the number of bed bug infestations in recent years is conservatively estimated at 100,000, then the economic loss to Australia computes to A\$100 million and this is likely to be a gross underestimate. In light of the recent exponential growth in infestations, these costs are set to dramatically increase.

Most importantly, the figures above do not include any litigation; in the event of such action the above costs may seem insignificant to the individual accommodation provider.

Development of 'Best Practice'

The resurgence of bed bugs in Australia caught many unprepared; few in either the accommodation or pest management industry had any practical experience with bed bugs. Often bed bug control was not even often taught in pest control courses. The inevitable outcome with the return of the insects was that treatment failures were common, and poor pest control often resulted in the spreading of the infestation.

It was quickly recognised that an urgent priority was the education of pest managers and other affected stakeholders in proper bed bug management. To this end, in June 2005, a Working Party was formed under the auspices of AEPMA to develop a code of practice (CoP) for the control of bed bug infestations in Australia. The Working Party themselves consisted of noted pest managers, a published bed bug researcher, and representatives from University, an insecticide company and AEPMA. In terms of combined bed bug experience, the Working Party has undertaken close to 4,000 bed bug treatments.

The aim of the CoP was to provide a reference document, which would be a guide for pest managers, the accommodation industry and other affected stakeholders, on best practice in the control of active bed bug infestations and the management of potential infestations. The expected outcome from adherence to the CoP would be to minimise the impact of bed bug infestations wherever they occurred.

The Working Party attempted to ensure that the CoP was widely accepted. A draft of the first edition (Doggett, 2005b) was placed onto the web (www.bedbug.org.au) and stakeholders were encouraged to provide feedback. The Draft CoP was open for public comment for three months, and all submissions were considered by the working party and used in the development of the final release of the first edition (Doggett, 2006a). To ensure a level of openness, all submissions were placed onto the above web site and explanations were provided for the reason for the inclusion or exclusion of each submission into the final release of the CoP.

To encourage the use of best practice, the Working Party has provided the CoP free of charge to all stakeholders. As bed bugs are an international problem (and will require an international effort to be overcome), other pest management associations have been welcome to use the CoP. The Pest Management Association of New Zealand and the Confederation of European Pest Associations have now adopted the CoP.

In order to maintain relevance, the Working Party has decided to review the CoP on an annual basis until the bed bug problem abates, and to incorporate the latest advances in research and management technologies for this pest. A draft second edition of the CoP was released in July 2007 for public comment (Doggett, 2007a), and the final version of the second edition was released in November 2007 (Doggett, 2007d).

Education

An important strategy in combating bed bugs in Australia is the education of the various stakeholders in the proper management of bed bugs. The Department of Medical Entomology has produced numerous papers (17) for various industries journals, including the following groups; pest managers, hotel/motel management, housekeepers, student accommodation managers, hotel engineers and environmental health officers. The publications are listed in the references under Doggett and colleagues. Likewise, the Department has given around 50 separate presentations to such groups. In mid-2008, a one day bed bug training course will be taken around the country. This course will cover both theoretical and practical components of bed bug management, with the curriculum based on 'best practice' as defined by the CoP. Pest managers who complete the course will be eligible for continuing professional development points.

Research

The first strategy in the war against bed bugs in Australia mentioned above was to define the problem, the second to develop best practice in bed bug management and the third to educate on best practice. Best practice however, can only be based on current management technology and, for bed bugs, technological innovations in management lag well behind other arthropod pests. Research is urgently needed in the areas of both non-chemical and chemical control, and also for the rapid detection of infestations. Bed bug research in Australia is in its relative infancy and the following discusses the investigations to date.

Non-chemical control. The development of the CoP led to the recognition that knowledge in many areas of non-chemical bed bug management was deficient. This included the proper use of steam, the use of devices such as the Cryonite, and the 'folk remedies' such as the wrapping of infested items in black plastic and placement in the sun for thermal energy to 'cook' the bugs. The latter method has often been touted by pest managers, pest management texts (e.g. Hadlington and Gerozisis, 1985) and health officials (e.g. VDHS, 2007), despite a lack of scientific substantiating evidence. The results of the non-chemical control investigations have been to evolve the CoP and the current edition has been substantially enhanced since the initial draft, especially in the use of steam. The Cryonite, which is a machine that employs carbon dioxide 'snow', was found often not to be lethal and in the process, bed bugs are regularly blown away from the treatment area. As this device represents a risk of spreading infestations, it has not been recommended for use within the CoP.

To examine the black plastic theory, two mattresses were tested; a basic 8cm thick foam rubber mattress, and a 32cm thick multilayered inner spring mattress that had a padded layer on both the top and bottom (Doggett et al., 2006). Data loggers were placed on both sides to accurately record the temperature changes over time and the mattresses were then wrapped in black plastic and placed outside on a sunny hot Sydney summer day. On the day of the experiment, the air temperature peaked at 36°C and remained above 30°C

from 11:00am until 3:30pm. The temperature on the sun exposed side of both mattresses reached 85°C; however, the underneath did not reach 44°C, with the highest reading being 41.5°C for the foam mattress (Figure 11) and less than 35°C for the thicker mattress (Figure 12). These results indicated that black plastic should not be relied on for control bed bugs on mattresses and this method is thus not recommended within the CoP.

Insecticide efficacy studies. The Department of Medical Entomology currently has both common bed bug, *C. lectularius*, and Tropical bed bug, *C. hemipterus*, in colony. The former was derived from various Sydney infestations during 2004, while the latter from infestations in northern QLD in 2004. While not yet specifically quantified against known susceptible strains, it appears that these Australian strains are highly resistant to SPs. Efficacy studies on these colonies have been focused on testing candidate products not currently registered in Australia for bed bug control and include the following investigations.

The chitin synthesis inhibitor, triflumuron 480 (480 g/L triflumuron), was tested against the common bed bug, *C. lectularius*. First instar nymphs were placed on filter paper treated at the doses equivalent to 1 ml and 2 ml product/L (diluted in water). These doses are the currently registered application rates as employed against other insects. There was also an untreated control. The bugs were offered a blood meal weekly, with blood feeding, moulting and mortality recorded. In the controls and both test doses, the bugs developed into the adult stage with no significant difference in mortality. Thus at the above does rates, triflumuron 480 was not found to be effective.

The efficacy of diatomaceous earth (DE) was tested using adult and 1st instar nymphs of the Common bed bug, at rates equivalent to 1, 2, 4, and 8 g/m². The results are depicted in Figures 13 and 14. In the case of the adult bugs, 100% mortality was achieved with the highest dose by Day 9 post exposure and by Day 15 for all doses. The 1st instar nymphs were more sensitive; 100% mortality occurred with the high dose by Day 3, and by Day 9 with all the doses. The greater sensitivity of 1st instar nymphs compared with the adults was not unexpected. The mode of action of DE is to absorb lipids in the protective waxy surface of the insect cuticle, which leads to the loss of water and eventual death through dehydration (Quarles and Winn, 1996). Recently, Benoit (2007) found that 1st instar nymphs lose water at a much faster rate than latter instars and thus it would be expected that the younger nymphs would die more quickly when exposed to DE.

DE has a number of benefits over more traditional insecticides and hence these results appear promising. This includes low mammalian toxicity and the low possibility of resistance (DE is not listed by the International Resistance Action Committee). Perhaps DE's greatest advantage is its long residual activity (possibly years) and it could be used in a prophylactic sense, i.e. applied to rooms that have yet to experience bed bugs so that if the insects are introduced, the possibility of the development of large infestations may be reduced.

Efficacy testing has been undertaken involving common bed bugs placed onto mattress fabric treated with various residual SPs. Prior testing of these products by other laboratories indicated that the treated mattress fabric was effective at controlling bed bugs. However, these earlier studies were undertaken on insecticide susceptible strains rather than resistant strains. When tested against the Australian strain of common bed bugs, none of the SPs were efficacious and it appears that treating mattress fabric is not an effective way of controlling bed bugs (a sublethal dose may even encourage resistance). These investigations also show that insecticide efficacy studies must be undertaken on appropriate bed bug strains, namely those that are recently field-derived and resistant, to ensure that data are relevant.

Pilot investigations testing the efficacy of neat Tea Tree oil against common bed bugs found this product to be ineffective.

International Cooperative Research. The Department of Medical Entomology has provided bed bug samples (all *C. lectularius*) to eight other research groups, both locally and internationally, for various projects including research on endosymbionts, phylogenetic analysis and insecticide efficacy investigations, and for museums as reference specimens. Of the endosymbiont testing, 90% of Australian Common bed bugs are infested with *Wolbachia* and 80% with a gamma proteobacterium (Jason Lo, University of Sydney, unpublished data) and all have at least one of these. Only recently, researchers have found some Common bed bugs infested with an *Ehrlichia* (John Stenos, Australian Rickettsia Reference Laboratory, unpublished data). At this stage it is not known if the *Ehrlichia* is an endosymbiont or acquired from a blood meal.

CONCLUSIONS

For the immediate future it is clear that bed bugs infestations will continue to be increasingly common and it is likely that they will remain a nuisance public health pest for many years to come. In light of this, the strategies mentioned herein will need to be continually re-evaluated, refined and developed. Surveys will need to be repeated in order to monitor the degree of the pest problem in various regions. Education and training of pest managers, the accommodation industry and other stakeholders in best practice management is essential in order to ensure proper control is undertaken, which in turn should minimise the spread of the insect. The CoP will need to evolve with the latest technological advances. Finally, research is needed to find the most effective methods in monitoring bed bug populations, eradicating active infestations and minimising the risk of new infestations. Bed bugs were largely defeated during the years post WWII with the advent of the OCs. No single group of insecticide or insect control methodology will defeat this current resurgence and only a concerted cooperative effort is likely to succeed.

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