Back with a Bite: Bed Bugs 25 Years On!

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Back with a Bite: Bed Bugs 25 Years On!

The Global Bed Bug Resurgence began 25 years ago, but what have been the major highlights and research initiatives?

Stephen L. Doggett & Richard Cooper

In the dead of night, they emerge—a creeping tide of tiny predators that have haunted the annals of sleepy-time tales and now, the modern bedroom. The bed bug, a pest thought to have been all but vanquished in the mid-20th century, has made an unwelcome return to the global stage. This article pulls back the sheets on the last 25 years, examining how these bloodthirsty insects have crept back into our mattresses, our lives, and our nightmares.

The resurgence of bed bugs has not just been a minor inconvenience; it represents a complex intersection of global travel, urban living, and, most importantly, pesticide resistance. This article aims to explore the major developments in the bed bug saga, examining their subtle return and the reasons behind this. It will also review the crucial science and efforts undertaken to combat this pest. Importantly, many bed bug management techniques were implemented before their effectiveness was scientifically verified. These methods only gained widespread acceptance after being published and scientifically improved. In this context, the year of first publication is considered the benchmark for each milestone.

The global journey of these nocturnal nuisances will be traced over the past quarter-century, highlighting the key breakthroughs in the ongoing war against the bed bug—and what it could mean for the future of our peaceful slumber. Despite numerous technologies and methods of control having emerged, one question remains: *Are we any closer to putting the bed bug resurgence to rest*? Something to ponder at the end of this article!

1998: First Suggestion of a Resurgence

The global resurgence of bed bugs likely started well before the dawn of the new millennium in 2000. Reports from the 1980s and 1990s in Africa indicated that many villages were plagued by insecticide-resistant bed bugs. However, it was a medical report in 1998 from Cambridge, England, that first hinted at a resurgence. This report suggested an increasing bed bug problem in the university town and noted the ineffectiveness of insecticides. Unfortunately, the report did not include any supporting data.

Birchard K. (1998). Bed bugs biting in Britain: only rarely used pesticides are effective. *Medical Post*, 34: 55.

1998: Spread of the Tropical Bed Bug

In early 1998, specimens of the tropical bed bug, *Cimex hemipterus*, were sent to the Department of Medical Entomology at Westmead Hospital in Sydney, Australia. These specimens were collected from a café adjacent to a backpacker's

lodge in Northern Queensland, marking the first recorded presence of this species in the country. Shortly thereafter, the tropical bed bug was found in other parts of Australia, as well as in various regions around the world where it had not been previously reported.

Doggett S.L., Geary M.J., Crowe W.J., Wilson P. and Russell R.C. (2003). Has the Tropical Bed Bug, *Cimex hemipterus* (Hemiptera: Cimicidae), invaded *Australia? Environmental Health*, 3: 80-82.

The modern bed bug resurgence has involved two species; the common bed bug (*Cimex lectularius*) and the tropical bed bug (*Cimex hemipterus*) above.

1999: Bed Bugs Found in Egyptian Digs

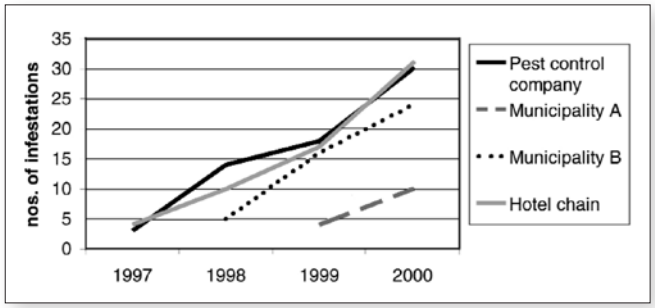
This paper, while not directly related to the modern resurgence, highlights the long history of human encounters with bed bugs. Researchers conducting excavations in Egypt from the era of the Pharaohs discovered bed bugs in dwellings dating back to 1352-1336 BCE. Although the authors identified the species as the common bed bug, *Cimex lectularius*, the images in the paper reveal that the specimens were not completely intact. Therefore, the possibility of them being the tropical bed bug, *Cimex hemipterus*, cannot be dismissed.

Panagiotakopulu E., Buckland P.C. (1999). *Cimex lectularius* L., the common bed bug from Pharaonic Egypt. *Antiquity*, 73: 908–11.

2001: First Data Confirming a Resurgence

Anecdotal reports suggesting that bed bugs were becoming more prevalent were made by several American authors between 1999 and 2000. However, the first report providing concrete evidence of the bed bug resurgence was written for a pest management magazine by Clive Boase, of the United Kingdom. In the article, he documented a rise in bed bug infestations as observed by a pest management company, two municipal councils, and a hotel chain from 1997 to 2000 (graph below). While the reports did not specify the species of bed bugs, it is generally assumed to be *Cimex lectularius*.

Boase C. (2001). Bedbugs - back from the brink. *Pesticide Outlook*, 12: 159-162.



2002: Resistance in the Tropical Bed Bug

Resistance in the tropical bed bug was first reported approximately 50 years before the study mentioned directly below. However, the significance of this paper lies in its observation of a change in resistance over a relatively short period. In malaria-prone regions of Tanzania, villagers were given bed nets impregnated with pyrethroids to prevent mosquito bites. Initially, the bed bugs vanished with the introduction of these nets, but after six years, they reappeared. Subsequent research demonstrated that these bed bugs had developed a high level of resistance to permethrin and alphacypermethrin.

Myamba J., Maxwell C.A., Asidi A., Curtis C.F. (2002). Pyrethroid resistance in tropical bedbugs, *Cimex*

RESURGENCE

- **1998** — Hint of a Resurgence
- **1998** — Tropical BB Spread
- **1999** — BBs in Egyptian Digs

- **2004** — Resurgence Goes Global
- **2004** — First Modern Forum
- **2004** — First Academic Talks
- **2006** — Non-chemical Control
- **2006** — 'No-Prep' Method
- **2007** — Resistance Mechanism Identified

- **2008** — BBs Spread in Buildings
- **2008** — Historical Management Article
- **2008** — Bed Bug TV

HIGHLIGHTS

- **2001** — Data Confirms Resurgence
- **2002** — Resistance in Tropical BB
- **2003** — Landmark Litigation
- **2005** — First Industry Standard
- **2005** — First Academic Symposium
- **2006** — Resistance Identified

- **2007** — Modern Handbook
- **2007** — Mattress Encasement Study
- **2008** — Detection Dogs Tested
- **2009** — Pitfall Traps Tested
- **2009** — Infestations Quantified

- **2010** — First American Summit

RESURGENCE

- 2011 — Critical Product Review
- 2012 — Infestations Start with One BB!
- 2012 — Novel Biopesticide
- 2012 — Dual Action Insecticides
- 2012 — Effective Chemical Lure
- 2013 — Desiccant Dusts Transfer
- 2015 — Aggregation Pheromone Found
- 2015 — Low Income Housing Management
- 2017 — Trop BBs Have Hairy Feet!

- 2018 — Control Failures Explained
- 2020 — COVID-19 Outbreak
- 2021 — BBs Linked to Malaria Rise?

HIGHLIGHTS

2012 Landmark Clinical Paper

2012 New Help Guide

2012 Dispersal Patterns Revealed

2014 Silica Dioxide Emergence

2015 BB Movements in Apartments

2015 Super-*kdr* Identified

2017 Practical Advice for Pitfalls

2017 Response to Dusts

2018 First Academic Text in 50 Years

2023 Group Test Debated Product

2023 Lethal Harbourage Trap

2023 Paris Media Explosion!

hemipterus, associated with use of treated bednets. *Medical and Veterinary Entomology*, 16: 448-451.

2003: Early Landmark Bed Bug Litigation

The Mathias versus Accor case gained notable recognition in U.S. legal circles, early in the modern bed bug resurgence. In summary, a brother and sister, while staying at the Accor hotel's Red Roof Inn in Chicago, were severely bitten by bed bugs and subsequently sued the hotel for damages. The court ruled that the hotel's conduct was 'wanton and willful,' as they were aware of the bed bug infestation but failed to take the necessary management steps as recommended by their pest manager. The hotel also declined to close infested rooms for treatment, and in one instance, a guest was moved to three different rooms, each infested with bed bugs. Furthermore, the hotel knowingly rented out these infested rooms. The court ordered the hotel to pay each plaintiff $5,000 in compensation and $186,000 in punitive damages, totalling $382,000. The decision was appealed but ultimately upheld.

This case set a precedent for numerous subsequent bed bug litigation cases in the U.S., some involving class actions settled for over several million dollars. It also underscores the potential reputational damage businesses can suffer when such issues become public. Notably, such extensive litigation has largely been confined to the United States.

Mathias v Accor Economy Lodging. (2003). United States Court of Appeals for the seventh circuit. https://www.casebriefs.com/blog/law/torts/torts-keyed-to-franklin/damages-and-insurance/mathias-v-accor-economy-lodging-inc/

2004: The Resurgence Goes Global

A 2004 paper from Australia, with Stephen Doggett as the lead author, demonstrated that the bed bug resurgence was not confined to the UK and US. The article reported that his Department had observed a more than 400% increase in bed bug sample submissions to its pathology service since early 2001. Additionally, it noted that one pest control company experienced an almost 700% rise in bed bug treatment services between 2000 and 2004. The Australian Quarantine and Inspection Service also reported a significant increase in bed bug interceptions in travellers' luggage. This was the first peer-reviewed publication with evidence of the resurgence.

Doggett S.L., Geary M.J. and Russell R.C. (2004). The resurgence of bed bugs in Australia, with notes on their ecology and control. *Environmental Health*, 4: 30-38.

2004: The First Modern Bed Bug Forum

The Whitsundays in Queensland, Australia, a tropical region popular among young backpackers and tourists, was one of the first areas in the nation to be severely affected by bed bugs. In 2004, several backpacker hostel chains reported hundreds of their beds were infested with bed bugs. In Sydney, a late 2003 survey found that nearly 80% of backpacker accommodations had experienced at least one infestation. The situation was particularly dire in the Whitsunday region, primarily due to *C. hemipterus* (the tropical bed bug), with infestations spreading to areas frequented by backpackers, including charter vessels. One pest manager reported conducting 370 treatments in 1999 alone at a single staff accommodation facility in the area.

The severity of the issue led the local council to host a two-day forum, making it the world's first conference focused on modern bed bug issues, to discuss the problem and develop strategies for mitigation. However, this attention had an unintended consequence: the region, and the backpacking industry as a whole, quickly became associated with bed bugs. This led to a reluctance to report further infestations, driven by concerns over the impact on tourism.

2004: First Presentations to Academia

Before 2004, reports on the bed bug resurgence were primarily published in pest management industry journals, resulting in limited awareness among academics and a delay in initiating research efforts. That year marked a pivotal moment with key presentations bringing this issue to the attention of the academic community.

The first significant presentations were

by Richard (Rick) Cooper and Frank Meek (Orkin) at the 2004 National Congress on Urban Entomology in Phoenix, Arizona, a U.S.-based conference dedicated to research developments in urban pest management. In the same year, Stephen Doggett discussed his 2004 paper, as mentioned previously, at the International Congress of Entomology (ICE) in Brisbane, Australia. ICE is a major international event that occurs every four years and is the most prominent gathering for entomological researchers.

Rick's presentation was "*Bed Bugs More Questions than Answers: A Call for Research*" and was a persuasive argument to the academic community to recognize that bed bugs were becoming a significant pest of urban importance, and that research was desperately needed. Interestingly at Rick's talk, Michael Potter and Dini Miller were in attendance. The latter two researchers were also among the audience of Stephen Doggett's talk, along with Chow-Yang Lee, three academics who soon embarked on bed bug research and subsequently became leading figures in the field. It is likely that Rick's and Stephen's presentations helped facilitate these researchers to launch bed bug research programs at their respective Universities.

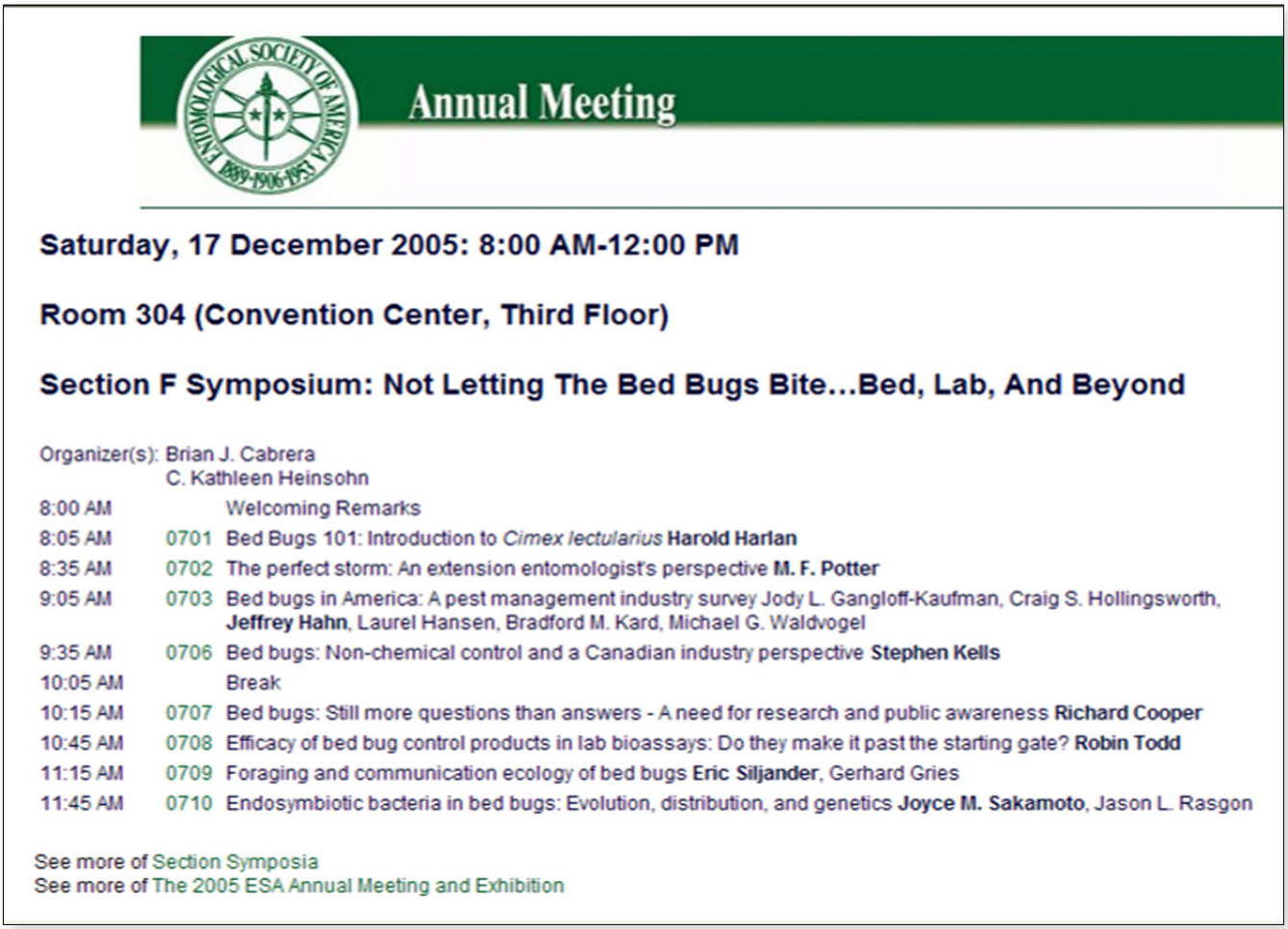
These instances underscore the importance of bridging the gap between pest industry trends and academic research, as demonstrated by the shift in focus following these presentations.

2005: First Bed Bug Industry Standard

As bed bug numbers rose and technicians repeatedly failed to control infestations, there was an urgent need for the industry to enhance its expertise in managing modern bed bugs. Initially, insecticide resistance was suspected as the primary cause of the resurgence, a hypothesis that was soon confirmed scientifically. However, it quickly became apparent that the magnitude of the resurgence was largely due to inadequate pest control practices.

In response to this challenge, the Australian Environmental Pest Managers Association (AEPMA) formed a working party in 2005 to develop a guide for best practices in bed bug management. Stephen Doggett was appointed Chief Editor, and the first draft, titled 'A Code of Practice for the Control of Bed Bug Infestations in Australia,' was released that same year. It wasn't until five years later that Europe would publish their own code of practice, and the NPMA in the

The Australian Code of Practice in 2005 (top left), was the first industry standard developed for the management of modern bed bugs. To date there have been nine versions of this document.



Annual Meeting

Saturday, 17 December 2005: 8:00 AM-12:00 PM

Room 304 (Convention Center, Third Floor)

Section F Symposium: Not Letting The Bed Bugs Bite...Bed, Lab, And Beyond

Organizer(s): Brian J. Cabrera
C. Kathleen Heinsohn

8:00 AM		Welcoming Remarks
8:05 AM	0701	Bed Bugs 101: Introduction to *Cimex lectularius* **Harold Harlan**
8:35 AM	0702	The perfect storm: An extension entomologist's perspective **M. F. Potter**
9:05 AM	0703	Bed bugs in America: A pest management industry survey Jody L. Gangloff-Kaufman, Craig S. Hollingsworth, **Jeffrey Hahn**, Laurel Hansen, Bradford M. Kard, Michael G. Waldvogel
9:35 AM	0706	Bed bugs: Non-chemical control and a Canadian industry perspective **Stephen Kells**
10:05 AM		Break
10:15 AM	0707	Bed bugs: Still more questions than answers - A need for research and public awareness **Richard Cooper**
10:45 AM	0708	Efficacy of bed bug control products in lab bioassays: Do they make it past the starting gate? **Robin Todd**
11:15 AM	0709	Foraging and communication ecology of bed bugs **Eric Siljander**, Gerhard Gries
11:45 AM	0710	Endosymbiotic bacteria in bed bugs: Evolution, distribution, and genetics **Joyce M. Sakamoto**, Jason L. Rasgon

See more of Section Symposia
See more of The 2005 ESA Annual Meeting and Exhibition

The first academic bed bug symposium was held in 2005 by the Entomological Society of America.

U.S. would publish Bed Bug Best Management Practices. The Australian code has since undergone nine revisions, incorporating new research findings and refining best practices.

The latest version, the fifth edition and ninth iteration, was released in 2022 under the title 'Industry Code of Best Practice for Bed Bug Management.' It is available online at https://tinyurl.com/3j69utzj. Notably, this version is nearly double the size of the original, reflecting the significant increase in research and knowledge since 2005.

Doggett S.L. (2005). A Code of Practice for the Control of Bed Bug Infestations in Australia. Sydney, draft. *Westmead Hospital & the Australian Environmental Pest Managers Association, Sydney, Australia.*

2005: First Academic Symposium

Less than one year from when the first two talks were presented at the NCUE meeting, the Entomological Society of America (ESA) hosted the first bed bug symposium at an academic conference in Fort Lauderdale, FL USA. The proceedings of this symosium were later published in the American Entomologist. Several presenters, including Richard Cooper, Michael Potter, and Stephen Kells, went on to conduct significant research on bed bugs and became internationally renowned in the field. Two years later, the ESA organized a second symposium in San Diego, where Richard Cooper and Stephen Doggett met for the first time.

2006: Insecticide Resistance Identified

Most researchers and field workers at the time suspected that insecticide resistance was the trigger behind the global resurgence and that most modern strains had some level of resistance. It wasn't until 2006 that Clive Boase and colleagues published the first scientific evidence. They collected three field strains of *Cimex lectularius* and exposed them to a dose of

bendiocarb and alphacypermethrin that killed 99% percent of a susceptible strain. The results were striking: in one strain, bendiocarb killed less than 30% of the bugs, and alphacypermethrin killed only 10%. In the other two strains, none of the bed bugs died. This research confirmed that modern bed bugs were indeed resistant to multiple classes of insecticides.

That same year, the first peer-reviewed paper was published that demonstrated resistant to the pyrethroids in the US (Moore and Miller, 2006).

Boase C. J., Small G., Naylor R. (2006). Interim report on insecticide susceptibility status of UK bedbugs. *Professional Pest Controller*, Summer: 6-7.

Moore, D.J., Miller, D. (2006). Laboratory Evaluations of Insecticide Product Efficacy for Control of *Cimex lectularius*. *Journal of Economic Entomology*, 99: 2080-2086.

2006: Non-chemical Management Promoted

After recognizing widespread resistance to traditional insecticides, alternative bed bug control methods like vacuuming, steam treatments, and thermal techniques became key in integrated pest management (Kells, 2006). These non-chemical methods, rooted in science, were crucial due to the ineffectiveness of insecticides. However, some myths, such as encasing mattresses in black plastic for solar heat treatment, were prevalent. This myth, particularly questionable for modern thick mattresses, was debunked in a study where mattresses wrapped in black plastic and exposed to the sun did not uniformly heat up, leaving the underside below the bed bug thermal death point (Doggett *et al*., 2006).

Subsequently, research in Florida led to advancements in bed bug control, focusing on determining the necessary temperatures for extermination and developing affordable containment heat treatment protocols. This involved using polystyrene sheeting to encase infested items and circulating heat, proving effective for treating furniture. This approach, costing under USD $400, highlighted the importance of scientifically backed, cost-effective methods in bed bug management, challenging and disproving earlier misconceptions (Pereira *et al*., 2009).

The more effective pest managers adopted non-chemical options early in the resurgence. One of the most effective is vaccuming, which can rapidly remove large numbers of bed bugs.

Kells S.A. (2006). Nonchemical control of bed bugs. *American Entomologist*, 52: 109-110.

Doggett S.L., Geary M.J. and Russell R.C. (2006). Encasing mattresses in black plastic will not provide thermal control of bed bugs, *Cimex* spp. (Hemiptera: Cimicidae). *Journal of Economic Entomology*, 99: 2132-2135.

Pereira R.M., Koehler P.G., Pfiester M., Walker, W. (2009). Lethal effects of heat and use of localized heat treatment for control of bed bug infestations. *Journal of Economic Entomology*, 102: 1182–1188.

Testing the myth of wrapping mattresses in black plastic and placing items outdoor in the sun to kill bed bugs. The thickness of the mattresses provides insulation and the lack of air circulation prevents this method from being effective.

2006: 'No-Prep' Method of Bed Bug Management

In the early stages of the bed bug resurgence, companies provided clients with detailed preparation instructions before treatment. In fact, it was believed that extensive preparation was required to effectively treat for bed bugs. These instructions were often overburdensome and unrealistic for most people to carry out and involved tasks like bagging and laundering clothes throughout the entire home, laundering linens, emptying drawers of all personal items, removing curtains, keeping clothing and personal items bagged for months, and the list goes on and on. Many severely infested locations were homes of elderly or disabled individuals who were unable to perform the extensive preparations required by many pest control companies. Unfortunately, such preparation can actually spread the infestation and complicate the control effort. Around 2006, Richard Cooper of Bed Bug Central introduced the 'no-prep' approach, which eliminates the need for preparation prior to the initial visit and limits client cooperation to actions specific to the infestation being treated, and that will have a direct impact on eliminating the bed bugs. This method was scientifically validated in 2015 by the research team at Rutgers University, followed by numerous other studies since that time, and is now employed by nearly half of the pest control industry in the United States.

Cooper R., Wang C., Singh N. (2015). Evaluation of a model community-wide bed bug management program in affordable housing. *Pest Management Science*, 72: 45-56.

2007: Resistance Mechanism Identified

Researchers from Sri Lanka found that modern strains of *Cimex hemipterus* were resistant to pyrethroids, organochlorides, organophosphates, and carbamates (Karunaratne *et al*., 2007). They found that a major contributing mechanism to the resistant was metabolic. In the following year, a US team identified both metabolic and knockdown resistance (*kdr*) in *Cimex lectularius* (Yoon *et al*., 2008). They pinpointed two specific *kdr* mutations: V419L and L925I. Subsequently, Zhu and colleagues discovered that these mutations were widespread across the USA. In 2015, Kai Dang while working in Stephen Doggett's laboratory in Australia (Dang *et al*., 2015) identified a third mutation, I936F, in historical museum specimens. This mutation conferred only a low level of resistance and was eventually overtaken in the field by the more resistant mutations. Cuticular resistance was subsequently identified (Lilly *et al*. 2016) and more recently, symbiont-mediated resistance (Soh and Singham, 2022).

Comprehensive reviews on insecticide resistance have been produced by Dang & colleagues (2017) and Romero (2018).

Karunaratne S.H.P.P., Damayanthi B.T., Fareena M.H.J., Imbuldeniya V., Hemingway J. (2007). Insecticide resistance in the tropical bedbug *Cimex hemipterus*. *Pesticide Biochemistry and Physiology*, 88: 102-107.

Yoon K. S., Kwon D.H., Strycharz J.P., Hollingsworth C.S., Lee S.H. and Clark J.M. (2008). Biochemical and molecular analysis of deltamethrin resistance in the common bed bug (Hemiptera: Cimicidae). *Journal of Medical Entomology*, 45: 1092-1100.

Zhu F., Wigginton J., Romero A., Moore A., Ferguson

K., Palli, R. *et al*. (2010). Widespread distribution of knockdown resistance mutations in the bed bug, *Cimex lectularius* (Hemiptera: Cimicidae), populations in the United States. *Archives of Insect Biochemistry and Physiology*, 73: 245-257.

Dang K., Toi C.S., Lilly D.G., Bu W., Doggett S.L. (2015). Detection of knockdown resistance mutations in the common bed bug, *Cimex lectularius* (Hemiptera: Cimicidae), in Australia. *Pest Management Science*, 71: 914-922.

Lilly D.G., Latham S.L., Webb C.E., Doggett S.L. (2016). Cuticle thickening in a pyrethroid-resistant strain of the common bed bug, *Cimex lectularius* L. (Hemiptera: Cimicidae). *Plos One*, 11: e0153302.

Soh L.-S., Singham G. V. (2022). Bacterial symbionts influence host susceptibility to fenitrothion and imidacloprid in the obligate hematophagous bed bug, *Cimex hemipterus*. *Scientific Reports*, 12: 4919.

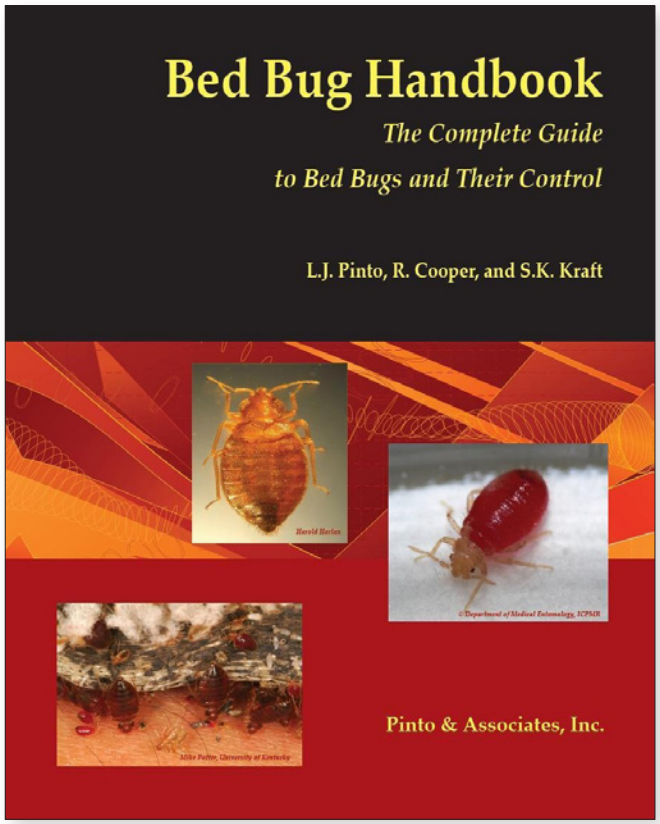
Dang K., Doggett S.L., Singham G.V., Lee C.Y. (2017). Insecticide resistance and resistance mechanisms in bed bugs, *Cimex* spp. (Hemiptera: Cimicidae). *Parasites & Vectors*,10: 318.

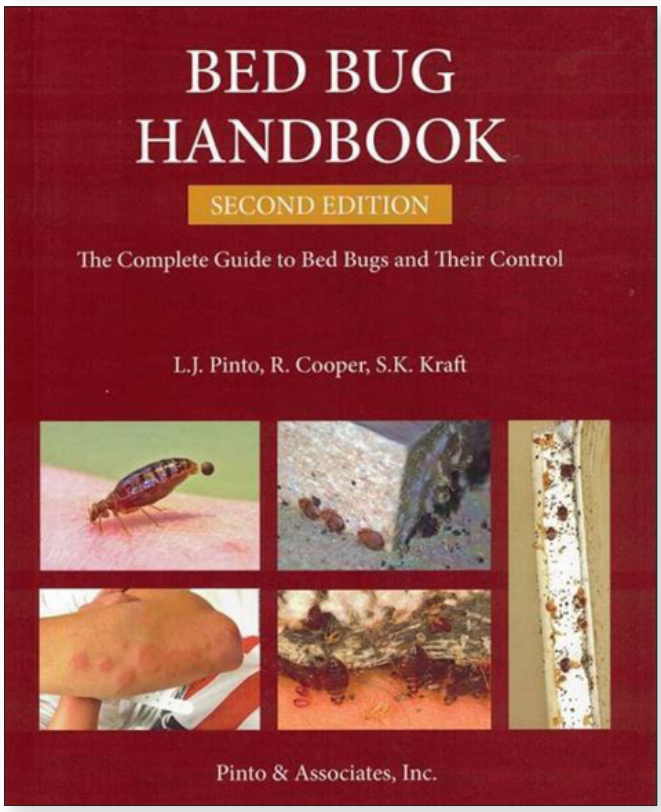
Romero A. (2018). Insecticide resistance. In *Advances in the Biology and Management of Modern Bed Bugs*, pp 421–427.

2007: Modern Bed Bug Handbook

In the early stages of the resurgence, as modern resistant bed bugs proved very difficult to eliminate, it was recognized that a three-pronged strategy was essential for long-term bed bug control. This strategy involved researching more effective control methods, establishing best practices for management, and promoting and educating the industry and affected stakeholder groups about these best practices. Against this backdrop, the emergence of a new text focusing on the control of modern bed bugs was particularly timely.

'The Bed Bug Handbook' was designed to be a comprehensive resource on bed bugs, encompassing their history, biology, methods of spread, societal impact of infestations, and extensive discussion on bed bug management in a wide variety of settings. It included detailed strategies for prevention and management, targeting professionals in pest control and facility management. The book was updated in 2021, with a second edition being released to reflect the latest developments and insights in the field.





The first edition (top) of the Bed Bug Handbook was released in 2007, the second in 2022. These were designed to be comprehensive resources for the management of bed bugs.

Pinto L.J., Cooper R., Kraft S.K. (2007). Bed Bug Handbook: The Complete Guide to Bed Bugs and Their Control. *Pinto & Associates, Mechanicsville, MD, USA*.

Pinto L.J., Cooper R., Kraft S.K. (2021). Bed Bug Handbook: The Complete Guide to Bed Bugs and Their Control, second edition. *Pinto & Associates, Mechanicsville, MD, USA*.

2007: Mattress Encasement Study

For centuries, reducing and sealing cracks and crevices has been recognized as a crucial method for minimizing bed bug presence. However, the numerous hiding places associated with mattresses and mattress bases have historically posed a significant challenge in removing bed bugs from beds. Discarding them is costly, both in terms of replacement and disposal, and new mattresses risk becoming infested. Additionally, treatment of mattresses with insecticides is questionable and many people are uncomfortable sleeping on beds where insecticides have been applied. Around 2007, mattress encasements emerged as a viable solution. A snug fitting encasement eliminates most hiding places, allowing for easier detection and removal of bed bugs, which makes for a more efficient and effective inspection of the bed complex during follow-up visits. Furthermore, encasements can be used on infested mattresses to trap the bugs inside, preventing the need to dispose of infested mattresses. Some encasements even feature bite-proof membranes, ensuring that any trapped bed bugs will eventually starve.

By 2007, there were at least half a dozen encasements on the market, but no research had been conducted to determine which was most effective. Richard Cooper embarked on a comprehensive investigation of mattress encasements, examining aspects such as whether first instar bed bugs could escape through zippers, or the zipper end stops. He found that, at the time Protect-A-Bed was one of the best options. Richard presented his findings at the 2007 bed bug symposium of the Entomological Society of America's annual meeting and published an article on the subject in a US trade journal. Since then, some manufacturers of encasements for bed bugs have modified their designs to overcome the limitations raised by Rick.

A snuggly-fitted mattress encasements provides bed bugs with fewer harbourages.

It is important to note that later research by Richard Naylor and later by Shannon Sked (see 2012 below) questioned the potential of mattress encasements altering bed bug distribution patterns.

Cooper R.A. (2007). Just encase: mattress and box spring encasements can serve as an essential tool in effective bed bug management. *Pest Control Magazine*, 75: 64-66, 70, 72-75.

2008: Bed Bug Detection Dogs Tested

Detecting low-level bed bug infestations presents a significant challenge due to the insect's elusive nature. In 2006, the pest industry began exploring the use of dogs trained to detect bed bugs, a concept borrowed from their use in termite detection. Research by the University of Florida in 2008 showed promising results: in laboratory settings, dogs were 95% accurate in identifying live bed bugs and viable eggs, with only a 3% false positive rate for bed bug faeces (Pfiester *et al*., 2008). Further testing in simulated hotel environments reinforced these findings, with dogs achieving 98% accuracy in locating live bed bugs and no false positives.

However, the effectiveness of these canine detection teams in real-world scenarios was less clear. Richard Cooper and the team at Rutgers

Bed bug detection dogs were used since the first decade of the bed bug resurgence. Even though they were found to be not as accurate as first suggested, they can rapidly check large areas for bed bugs. Pictured is an aid for training dogs. Bed bugs are placed into one of the buckets and the dog needs to alert on the positive location.

(2014) conducted field tests in naturally infested apartments and found that while handlers believed their dogs were over 95% accurate, the average detection rate was actually only 44%, with a 15% false positive rate. This stark contrast between laboratory and field results emphasizes the importance of extensive testing in both environments before fully endorsing a method. It also illustrates how research conclusions can evolve over time, in this case taking six years to fully assess the efficacy of bed bug detection dogs.

Pfiester M., Koehler P.G., Pereira R.M. (2008). Ability of bed bug-detecting canines to locate live bed bugs and viable bed bug eggs. *Journal of Economic Entomology*, 101:1389–1396.

Cooper R., Wang C., Narinderpal S. (2014). Accuracy of trained canines for detecting bed bugs (Hemiptera: Cimicidae). *Journal of Economic Entomology*, 107: 2171-2181.

2008: Bed Bug Spread Through Buildings

Stephen Doggett and colleagues presented a graphic illustrating the spread of bed bugs through a hospital staff accommodation block comprising approximately 320 separate apartments. The infestation, which started in a single room in 2003, had spread to over 20% of the apartments by 2005. Most infested rooms were adjacent to another infested room. Poor pest control and inadequate management processes were identified as key factors facilitating the spread of bed bugs. This particular infestation, possibly originating from a single introduction, led to the recommendation in the Australian Code of Practice that all units adjoining an infested premise in apartment complexes should be inspected.

In a similar study, Changlu Wang and colleagues in the U.S. examined bed bug spread in a high-

rise apartment complex with 223 units. Within 41 months of the first reported infestation, bed bugs had spread to 45% of the units. The use of pitfall traps revealed that 78% of the captured bed bugs were nymphs. On average, six bed bugs were detected dispersing through apartment entry doors. Adults were found to be nine times more likely to disperse than nymphs. Over half of the infested units were adjacent to another infested unit, and significantly, 50% of residents were unaware of the infestation in their premises. As the paper noted, these findings underscored the importance of early detection, public education, and more effective bed bug monitoring.

Doggett S.L., Russell R.C. (2008). The resurgence of bed bugs, *Cimex* spp. (Hemiptera: Cimicidae) in Australia. In: *Proceedings of the Sixth International Conference on Urban Pests, Budapest, Hungary, 13-16 July 2008, edited by W. H. Robinson and D. Bajomi.*

Wang C., Saltzmann K., Chin E., Bennett G.W., Gibb T. (2010). Characteristics of *Cimex lectularius* (Hemiptera: Cimicidae) infestation and dispersal in a high-rise apartment building. *Journal of Economic Entomology*, 103: 172–177.

2008: Bed Bug TV with Jeff White

Jeff White (below) of BedBug Central, (founded by Richard Cooper and his brother Phil) created BedBug TV (available at www.youtube.com/@BedBugCentralTV/videos) to educate the industry and consumers alike on a wide variety of topics about bed bugs and their management. As the host of Bed Bug TV, Jeff produced approximately 154 videos, which garnered over 6.3 million views with the last episode airing in 2020. The production of BedBug TV ceased, following Jeff's departure from BedBug Central in 2021.

2009: Pitfall Traps Tested

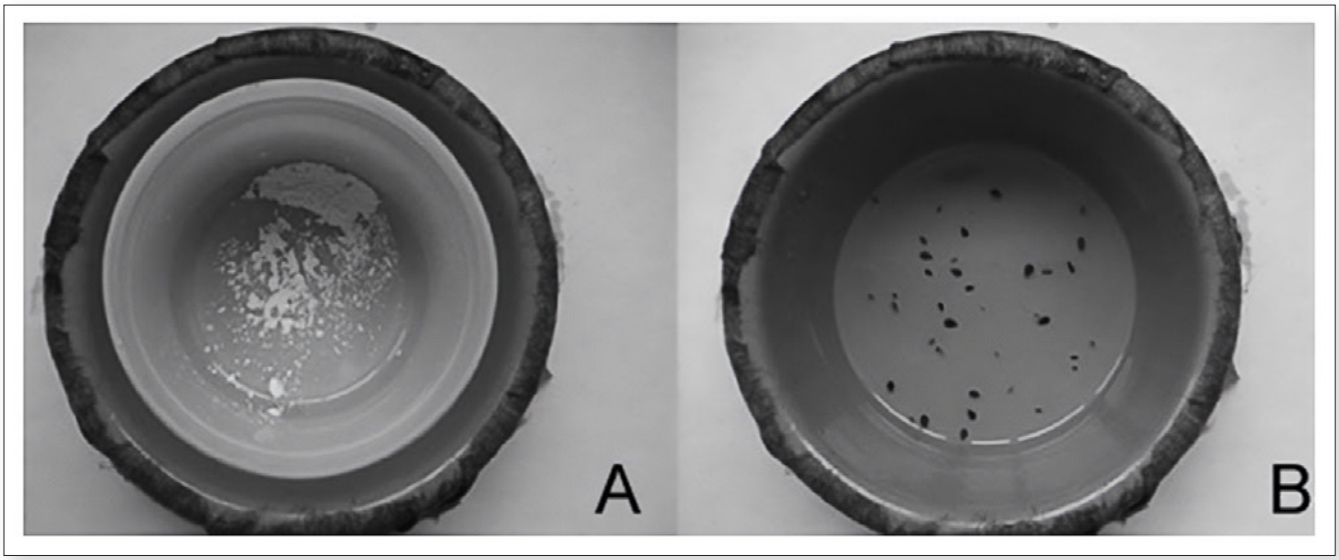
The concept of pitfall traps for bed bugs dates to the early 1940s, drawing inspiration from the earlier practice of placing bed legs in tin cans filled with grease or kerosene to prevent bed bugs from reaching a sleeping person. The key innovation in modern pitfall traps is their dual function: they not only act as barriers but also serve as monitors for bed bug activity. Changlu Wang and colleagues were the first to field-test a pitfall trap in 2009. They concluded that these traps were more effective in detecting bed bug infestations than visual inspections, a result that has been repeatedly demonstrated in field studies conducted by several other researchers. Additionally, they have been invaluable in studying bed bug movement within and between apartments (see 2015 below). Pitfall traps are more commonly used in the U.S. than in other countries.

Wang C., Gibb T., Bennett G.W. (2009). Evaluation of two least toxic integrated pest management programs for managing bed bugs (Heteroptera: Cimicidae) with discussion of a bed bug intercepting device. *Journal of Medical Entomology*, 46: 566-571.

2009: Bed Bug Infestations Quantified

Speakers at meetings often showcase extreme examples of bed bug infestations, where bed bugs infest every item, cast skins accumulate, and faecal stains are widespread. While these images are striking, they do not represent the average infestation. To quantify more typical infestations, Changlu Wang and colleagues conducted a study in 2009 in 16 infested low-income apartments. They discovered that the average infestation contained about 75 bed bugs. Further research in 2016, using pitfall traps in similar settings, found that most infested apartments captured only 1-10 bed bugs. It's well known that low-income housing, particularly in apartment complexes, often experiences higher infestation rates and more severe cases. Conversely, hotels and private homes generally report lower bed bug counts.

Wang C., Gibb T., Bennett G.W. (2009). Evaluation of two least toxic integrated pest management programs for managing bed bugs (Heteroptera: Cimicidae) with discussion of a bed bug



The very first pitfall traps consisted simply of a cup within another cup (left, central cup removed on the right). Soon they were commercialised, with the ClimbUp being the first, later several other brands came onto the market.

intercepting device. *Journal of Medical Entomology*, 46: 566-571.

Wang C., Singh N., Zha C., Cooper R. (2016). Bed bugs: Prevalence in low-income communities, resident's reactions, and implementation of a low-cost inspection protocol. *Journal of Medical Entomology*, 53: 639-646.

2010: First American Bed Bug Summit

The bed bug frenzy had reached a peak in 2010. With bed bug research picking up, BedBug Central recognized the need to connect the academic community, pest industry, and most affected stakeholder groups. To meet this need, they created the BedBug University North American Bed Bug Summit, holding the first meeting in Chicago in 2010. The summit was the first of its kind, providing a forum focused on education and the sharing of knowledge across a variety of disciplines, including chemical ecology, behavioural ecology, insecticide resistance, molecular and genetic studies, social and mental health impacts, legal implications, the latest innovations in detection and control of bed bugs, and a variety of business related topics. The summit held annually between 2010 and 2012, featured the most influential scientists at the time, such as Michael Siva-Jothy, Klaus Reinhardt, Stephen Doggett, Richard Naylor, Chow-Yang Lee, Coby Schal, Michael Potter, Richard Cooper, Dini Miller, Joshua Benoit, Warren Booth, Kenneth Haynes, Stephen Kells, Phillip Koehler, Jeff White. In 2013, BedBug Central turned over the reins to the National Pest Management Association and would co-

In 2010, Bedbug Central held the first North American Bed Bug Summit. This became the premier bed bug training event for many years.

Stephen sitting in the Bedbug Central bed bug car (featuring tropical bed bugs!). This was at the second North American Bed Bug Summit in 2011.

sponsor the meeting rebranding it as the Global Bed Bug Summit. The meeting was held four more times over the next eight years with the last meeting held in 2020. A video recording of the 2010 meeting is still available for viewing on YouTube at: https://www.youtube.com/watch?v=5cOYEFjgaPA

2011: Historical Bed Bug Management Article

By 2011, bed bugs were almost universally acknowledged as one of the most challenging insects to exterminate. They not only exhibited high resistance to most chemical classes but also possessed multiple resistance mechanisms (with more to be discovered in the future). In search of more effective control methods, Michael Potter decided to revisit historical bed bug management techniques from a time before synthetic chemical insecticides were developed (Potter, 2011). Strategies such as minimizing hiding places and conducting thorough inspections, which were emphasized in older texts, remain relevant today. Potter later updated his paper in 2018. Additionally, a comprehensive review of historical bed bug management provided by Stephen Doggett and colleague Chow-Yang Lee was published as a two-part series in the FAOPMA Magazine, the first part released in 2023.

Potter M.F. (2011). The history of bed bug management-with lessons from the past. *American Entomologist*, 57: 14–25.

Potter M.F. (2011). Bed bugs through history. In *Advances in the Biology and Management of Modern Bed Bugs*. Wiley-Blackwell, Oxford, UK., pp. 9-25.

Doggett S.L. and Lee C-Y. (2013). Battling bed bugs through the ages: a historical journey of control strategies, Part I: Pre-insecticides. *FAOPMA Magazine,* July: 58-79. The second part will appear in the April 2024 issue of the *FAOPMA Magazine*.

2011: First Critical Review of Bed Bug Products

The worldwide rise in bed bug infestations

has led to an influx of products in the market. Unfortunately, many of these have prioritized profit over effectiveness. Some products had conceptual flaws, like permethrin-impregnated encasements which are largely ineffective against resistant strains. Other products were operationally flawed, such as high-pressure devices that claimed to freeze bed bugs but often resulted in dispersing bugs, while some are morally questionable. Additionally, many products were too complex to use, like certain CO_2 producing traps, or simply ineffective, such as glue traps that tend to repel bed bugs.

Few academics have been willing to openly criticize these products, resulting in their proliferation in the market, with some still available today. In 2011, Stephen Doggett addressed this issue in a consumer advocacy article, initially published in an Australian pest management industry publication, and later reprinted in a hotelier's journal and a British pest management magazine. He and co-author Mark Feldlaufer extensively updated this content for the 2018 textbook, "*Advances in the Biology and Management of Modern Bed Bugs*." Doggett considers this one of his most significant contributions, as it helped prevent many of these questionable products from entering the Australian market.

Doggett S.L. (2011). Bed bug products not always what they're cracked up to be. *Professional Pest Manager*, September: 31-32.

Doggett S.L., Feldlaufer M. (2018). Chapter 31. Limitations of bed bug management technologies. In: *Advances in the Biology and Management of Modern Bed Bugs. Wiley Blackwell, Oxford*, pp. 311-321.

2012: Chronic Infestations Start with One Insect!

In what could be considered one of the most critical research papers during the bed bug resurgence, researchers collected bed bugs from various units in chronically infested apartment buildings. They employed molecular techniques to ascertain the relationships between individual insects within each building. The study revealed that most infestations in these buildings originated from the introduction of a single bed bug, or very few introductions. This research underscored how the rapid increase in bed bug resurgence was largely due to poor pest management practices. It highlighted the urgent need for education and training in best practice bed bug management for all involved stakeholders.

Understanding historical bed bug management may provide insights on how we should conduct control today.

Booth W., Saenz V.L., Santangelo R.G., Wang C.L., Schal C., Vargo E.L. (2012). Molecular markers reveal infestation dynamics of the bed bug (Hemiptera: Cimicidae) within apartment buildings. *Journal of Medical Entomology*, 49: 535–46.

2012: Novel Biopesticide Tested

In response to the high resistance and difficulty in controlling modern bed bug strains, there was an urgent need for new insecticides. One such product that emerged was a biopesticide derived from *Beauveria bassiana*, a fungal pathogen of insects. Initial research was promising; bed bugs exposed to this

bioinsecticide died, and autodissemination occurred, where bed bugs killed by the product could transmit the fungal pathogen to untreated insects. This product was commercialized in 2017 and sold under the label of Aprehend, appearing to be a very promising innovation in controlling the global bed bug resurgence.

To date, there have been no published field trials to demonstrate the efficacy of this product, although anecdotal reports seem promising. However, there are concerns about its effectiveness in warmer climates, notably in situations without controlled temperatures. The spores of *Beauveria bassiana* are living organisms and perish at moderate temperatures. Therefore, the effectiveness of this product in warmer climates remains to be thoroughly investigated.

Barbarin A.M., Jenkins N.E., Rajotte E.G., Thomas M.B. (2012). A preliminary evaluation of the potential of *Beauveria bassiana* for bed bug control. *Journal of Invertebrate Pathology*, 111: 82–85.

2012: Landmark Clinical Paper

The paper by Stephen Doggett and colleagues, though not the first to address the clinical impact of bed bugs, was the most comprehensive in doing so. It effectively debunked common myths, such as the belief that bed bugs bite in threes, often described as 'breakfast, lunch, and dinner', for which there is no evidence. A significant strength of the paper was its discussion on why bed bugs do not transmit pathogens and evaluating the potential risk of bed bugs transmitting pathogens, concluding it to be negligible. This aligns with the statement from Jerome Goddard of the University of Mississippi, which remains valid: "*Even though bed bugs have been found naturally infected with many disease agents, they have never been proved to transmit even one.*"

Doggett S.L., Dwyer D.E., Penas P.F., Russell R.C. (2012). Bed bugs: clinical relevance and control options. *Clinical Microbiology Reviews*, 25: 164–192.

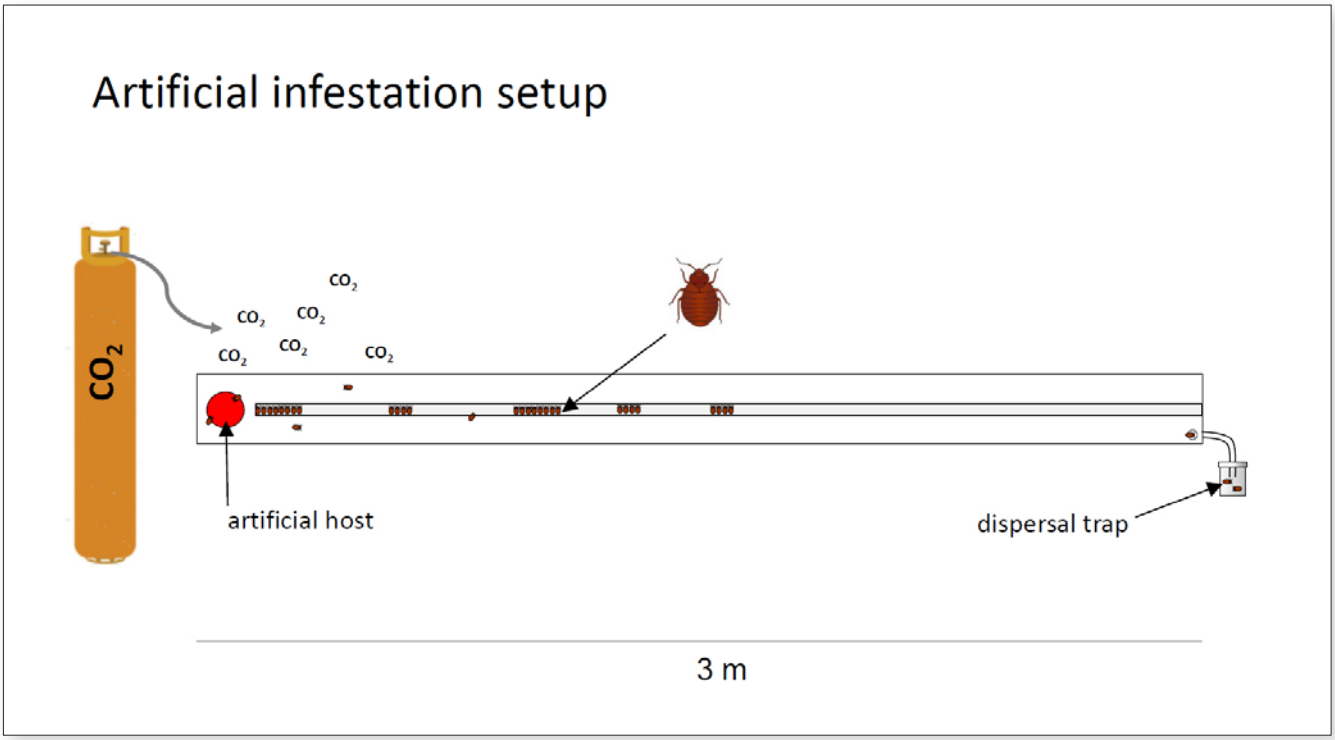
2012: Bed Bug Help Guide Released

In 2012, a 48-page pictorial guide for the identification of bed bugs was released (below). It featured images of bed bugs, common locations of infestations, and clinical images of bites. The guide was later published in seven languages, becoming the most widely sold book on bed bugs to date, with more than 12,000 copies printed. It's regrettable that the author didn't release this guide back in 2005 when the idea was first conceived!

Doggett S.L. (2012). Do you have Bed Bugs? A help guide for the identification of Bed Bugs. *Self-published, Sydney, Australia*. 48pp. Reprinted in Chinese, Japanese, Korean, Hindi, Norwegian, and Thai.

2012: Bed Bug Dispersal Patterns Revealed

In a significant study examining the biology of bed bugs, Richard Naylor from the UK investigated the dispersal and aggregation behaviour of *Cimex lectularius*. He set up a three-metre-long harbourage strip, released bed bugs at one end, and observed their distribution. His findings revealed that bed bugs initially use harbourages close to the host, with the infestation spreading as it grows. He also discovered that increasing the number of harbourages near the host delayed the bugs' dispersal, whereas fewer harbourages led to a quicker spread of the infestation. These insights have important implications for management strategies, such as using mattress encasements and sealing cracks and



Richard Naylor investigated bed bug dispersal and aggregation using a 3m long harbourage. His reseearch showed that a lack of harbourages near the bed can result in the infestation dispersing. This has implications for the use of encasements.

crevices near sleeping areas, which might inadvertently encourage bed bugs to disperse more actively. A more recent laboratory study by Shannon Sked, from Rutgers University, supports Richard Naylors concerns. The Rutgers study explored the impact of encasements on bed bug distribution, concluding the presence of mattress encasements caused a higher proportion of bed bugs to aggregate on bed frames and areas off the bed. Both studies (Naylor and Sked) were conducted in the laboratory, thus the implications of these studies on the management of bed bugs under naturally existing field conditions, is currently unknown and warrants future investigation.

In subsequent research, Richard also placed strips of cardboard around beds, which effectively minimized the spread of infestations, supporting his hypothesis. This approach could potentially be used as a control method (see 2023 paper on lethal harbourages). Regrettably, this impactful research was never formally published, resulting in its significance being largely unrecognized.

Naylor, R. (2012). Ecology and Dispersal of the Bedbug. ***Ph.D. Thesis, University of Sheffield, Sheffield, UK.***

Sked S., Ramos R., Cooper R., Abbar S., Pan X., Ranaghat S., Wang C. (2023). In case of encasements. *Pest Control Technology*, 51: 77-78, 80-82.

2012: Dual Action Insecticides Shown to be Effective Against Resistant Bed Bugs

In a significant advancement in pesticide technology, products combining neonicotinoids and pyrethroids were introduced, aiming to combat resistant bed bugs with their distinct modes of action. Initially, these formulations showed high efficacy against resistant strains in research led by Michael Potter's group (Potter *et al*., 2012), becoming a key component in bed bug management. However, their effectiveness was soon questioned by many practitioners. To investigate, Alvaro Romero and Troy Anderson focused on potential metabolic resistance to neonicotinoids in bed bugs, discovering in 2016 high resistance levels to several compounds, including acetamiprid and imidacloprid. This raised questions about whether this resistance had developed recently or had always been present but undetected.

Stephen Doggett, Dini Miller, and Rick Cooper in Korea, attending a bed bug symposium at the International Congress of Entomology, 2012.

Following this, resistance to another insecticide, chlorfenapyr, was reported in 2017 (Ashbrook *et al.*). The effectiveness of chlorfenapyr has been controversial, with research findings varying widely in terms of efficacy. Some studies reported high effectiveness, while others suggested minimal impact. This inconsistency highlighted the ongoing challenges in managing bed bug populations and the need for continual evaluation and adaptation of pest control strategies.

Potter M.F., Haynes K.F., Gordon J.R., Hardebeck E., Wickemeyer W. (2012). Dual-action bed bug killers. *Pest Control Technology*, 40: 62, 76.

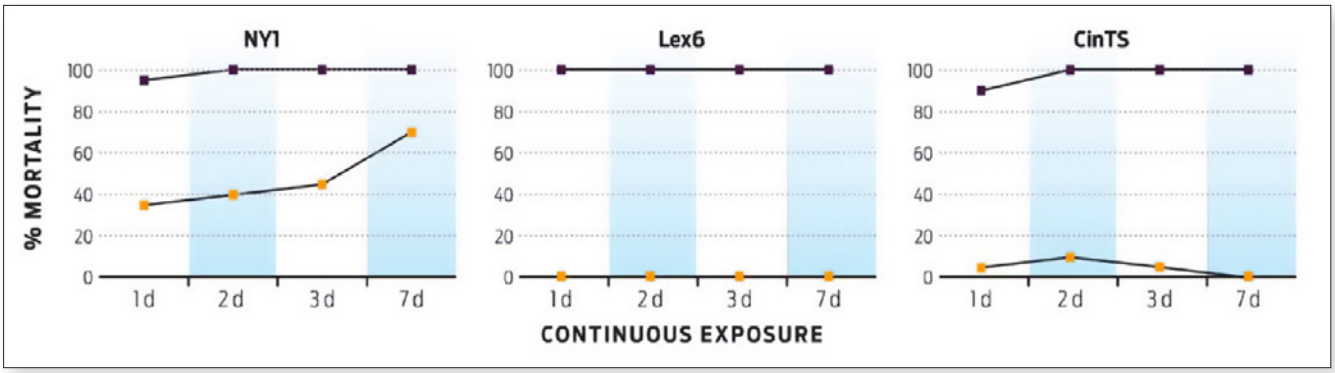
Romero A., Anderson T.D. (2016). High levels of resistance in the common bed bug, *Cimex lectularius* (Hemiptera: Cimicidae), to neonicotinoid insecticides. *Journal of Medical Entomology*, 53: 727-731.

Ashbrook A.R., Scharf M.E., Bennett G.W., Gondhalekar A.D. (2017). Detection of reduced susceptibility to chlorfenapyr- and bifenthrin-containing products in field populations of the bed bug (Hemiptera: Cimicidae). *Journal of Economic Entomology*, 110: 1195-1202.

2012: Chemical Bed Bug Lure Tested and Later Commercialised

The development of a trap that can attract bed bugs serves a dual purpose: it aids in monitoring infestations and potentially reduces their biomass, leading to more effective control. Such a device is also valuable for evaluating the success of treatments. Narinderpal Singh and his colleagues at Rutgers University developed an effective chemical lure that significantly increased trap catch when used in pitfall traps. The lure was later commercialized by BedBug Central under the name SenSci bed bug lure and marketed as a tool to enhance trap catch in commercially available monitors. While other chemical lures have been commercialized, this is the only product that has undergone in-field evaluation with the results published in a peer-reviewed journal.

Singh N., Wang C., Cooper R., Liu C. (2012).



Potter and colleagues in 2014 found that silica dioxide (upper line in the three graphs) produced a 100% kill in three resistant bed bug strains, whereas Temprid (neonicotinoid/pyrethroid combination) produced a poor kill when applied residually.

By marking, releasing, and recapturing bed bugs, Rick Cooper and colleagues gain valuable insights into the movements of bed bugs in aparments (see next page).

Interactions among carbon dioxide, heat and chemical lures in attracting the bed bug, *Cimex lectularius* L. (Hemiptera: Cimicidae). *Psyche*. doi:10.1155/2012/273613

2013: Horizontal Transfer of Desiccant Dusts

Insecticides that enable a transfer effect, leading to a secondary kill in untreated insects, have become fundamental in managing termites and cockroaches. Researchers discovered that diatomaceous earth dust (DED) could be transferred from treated to untreated bed bugs, resulting in a secondary kill (Akhtar *et al*., 2013). This finding suggests that even less thorough treatments with DED could be more effective than using other insecticidal products. However, subsequent studies raised doubts about the effectiveness of DED in real-world scenarios (as seen in research from 2017). Later, a similar transfer effect was also observed with silica dioxide (Singh *et al*., 2016).

Akhtar Y., Isman M.B. (2013). Horizontal transfer of diatomaceous earth and botanical insecticides in the common bed bug, *Cimex lectularius* L.; Hemiptera: Cimicidae. *Plos One*, 8: e75626.

Singh N., Wang C., Wang D., Cooper R., Zha C. (2016). Comparative efficacy of selected dust insecticides for controlling *Cimex lectularius* (Hemiptera: Cimicidae). *Journal of Economic Entomology*, 109: 1819–1826.

2014: The Emergence of Silica Dioxide

Silica gel, also known as silicon dioxide, was identified as effective against bed bugs as early as the 1940s. However, its use was not widespread, mainly because DDT, a highly effective insecticide, entered the market around the same time and became the preferred choice for bed bug control. Following the observed poor efficacy of diatomaceous earth dust (DED) and variable results with earlier forms of silica dust, researchers at the University of Kentucky revisited the efficacy of a new silicon dioxide formulation called CimeXa (Potter *et al*., 2014). They tested field-derived bed bugs against dry deposits of the dual-action insecticide Temprid and the CimeXa. While Temprid showed extremely poor efficacy, with two bed bug strains experiencing no deaths after seven days, all bed bugs exposed to CimeXa died within two days. More recently, a new silicon dioxide product, ChinCheX, has been introduced to the

market. It has been tested by laboratories in the UK, US, and Australia, with all confirming its high efficacy against resistant bed bug strains (these reports are available at www.chinchex.com). No other silicon dioxide product has been as extensively tested and universally proven effective.

Potter M.F., Haynes K.F., Gordon J.R., Washburn L., Washburn M., Hardin T. (2014). Silica gel: a better bed bug desiccant. *Pest Control Technology*, 42: 76, 84.

2015: Understanding Bed Bug Movements in Apartments

Limited research had been conducted on the dispersion of bed bugs within and between apartments. To investigate this, Richard Cooper and his colleagues at Rutgers conducted a series of "mark-release-recapture" studies. In these studies, bed bugs were captured, marked with coloured dots, released, and then recaptured over a period of 32 days to track their movements using pitfall traps. The findings revealed that bed bugs moved extensively within and between apartments, regardless of whether the premises were occupied. Their research demonstrated that bed bugs readily disperse away from host feeding sites and travel throughout apartments. Additionally, while active dispersal of bed bugs in multi-occupancy settings had long been suspected, this was the first study that definitively demonstrated active dispersal of bed bugs from infested apartments to neighbouring apartments. The entry points of apartments were identified as a major route for active dispersal. This research underscores the importance of inspecting all properties adjoining any infested unit, including those across the hall.

Cooper R., Wang C., Singh N. (2015). Mark-release-recapture reveals extensive movement of bed bugs (*Cimex lectularius* L.) within and between apartments. *Plos One*, 10: e0136462

2015: Super-Knockdown Resistance Found in the Tropical Bed Bug

Knockdown resistance (*kdr*) was previously documented in *Cimex lectularius*, but not in *Cimex hemipterus*. A multinational study involving tropical bed bugs from Africa, Australia, Malaysia, India, and Africa was conducted to search for mutations that might confer *kdr* resistance. This study identified four mutations, all different from those found in the common bed bug. As of 2023, 12 *kdr* mutations have been described in *Cimex hemipterus*. Notably, when the two mutations M918I and L1014F occur together, they confer 'super-*kdr*' resistance, a finding later confirmed by Dang and colleagues. In contrast, only three mutations have been identified in *Cimex lectularius*. The higher number of mutations in *C. hemipterus* could be attributed to its shorter reproductive cycle, allowing for quicker evolutionary changes. It's unsurprising then that the few studies directly comparing the two species indicate that *C. hemipterus* is more resistant and more difficult to exterminate with insecticides.

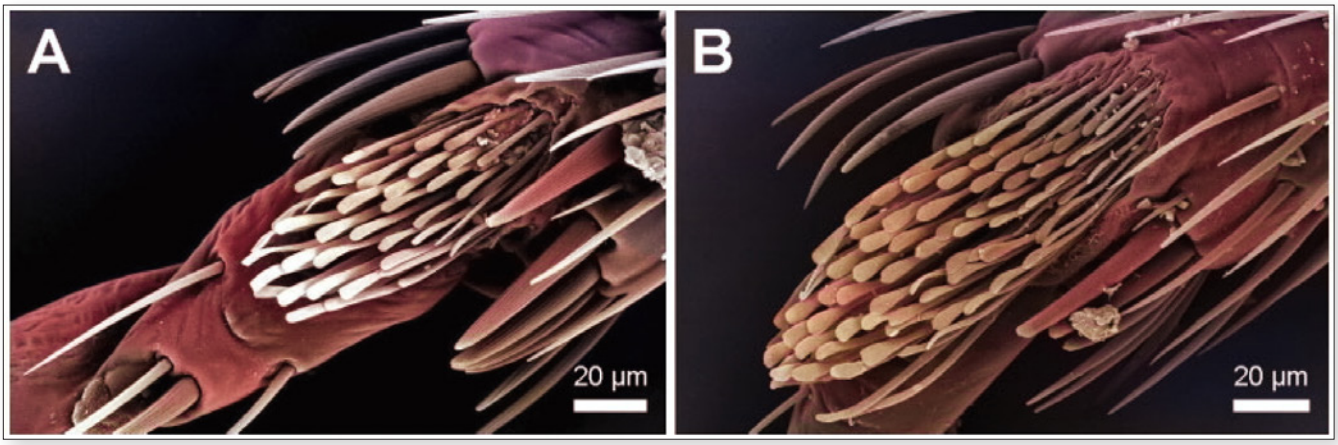
Dang K., Lilly D., Bu W., Lee C-Y, Naylor R. Tawatsin A., Thavara U., Doggett S.L. (2015). Identification of novel *kdr* mutations in the Tropical bed bug, *Cimex hemipterus* F. (Hemiptera: Cimicidae). *Pest Management Science*, 71: 1015-1020.

2015: Bed Bug Aggregation Pheromone Identified

It has long been understood that bed bugs emit pheromones in their hiding places, which help them return to these spots after feeding. Aggregating together aids in water conservation and facilitates mating. Canadian researchers discovered that the aggregation pheromone consists of five volatile components and one less volatile component. They found that these components, when combined, were highly effective at attracting bed bugs into traps.

Another fascinating aspect of their research is that the same chemicals used in the aggregation pheromone make up the alarm (dispersal) pheromone, only in different ratios. It will be interesting to see if either the aggregation or alarm pheromone leads to an effective monitoring or management strategy in the future, However, since these chemicals are volatile and have a short lifespan, they would need to be incorporated into a slow-release product or a synthetic analogue developed, to be effective over time.

Gries R., Britton R., Holmes M., Zhai H.-M., Draper J., Gries G. (2015). Bed bug aggregation pheromone



In 2017, Chris Kim and colleagues found that the tropical bed bug (right) possessed more tenant hairs on the tarsal pads than the common species (left). This 'hairy feet' adaption, enables the tropical species to climb smoother surfaces.

finally identified. *Angewandte Chemie International Edition*, 54, 1135–1138.

2015: Effective Management in Low-income Housing

The proliferation of bed bugs within affordable housing communities has and continues to be, a serious problem. Affordable housing for senior and disabled residents are of particular concern due to the severity of infestations and high infestation rates that often occur in these communities. Low quality pest management in the underserved sector, results in communities with high infestation rates and chronic infestations serving as reservoir for the spread of bed bugs into the external community. In the USA, as well as other parts of the world, low quality bed bug management is further promoted by a "low-bid" process, coupled with poorly written contract language, that encourages, pest management companies to base their bids on the least expensive methods, which are generally ineffective. Often, the end result is control failure and the continued spread of bed bugs. Researchers at Rutgers University, led by Richard Cooper, developed, and evaluated a 'community-wide Integrated Pest Management (IPM) program' specifically for such environments. This program included proactive monitoring and bi-weekly treatments of infested apartments using a combination of non-chemical and chemical control methods. When this program was tested in an affordable housing community, consisting of four buildings for senior and disabled residents, it resulted in a remarkable 98% reduction in bed bugs within one year. This successful approach serves as a model for comprehensive bed bug management in low-income housing.

Cooper R., Wang C., Singh N. (2015). Evaluation of a model community-wide bed bug management program in affordable housing. *Pest Management Science*, 72: 45-56.

2017: Tropical Bed Bugs Have Hairy Feet!

While working in Malaysia, Chris Kim discovered that tropical bed bugs (*Cimex hemipterus*) were more adept at escaping from pitfall traps compared to the common bed bug species (*Cimex lectularius*). Upon closely examining the feet of both species, it was found that the tibial pad of *C. hemipterus* possesses a greater number of tenent hairs, which provide increased friction force, allowing this species to traverse smoother surfaces more effectively. This finding has significant implications for monitoring the species using pitfall traps.

However, the reason behind this evolutionary adaptation in *C. hemipterus* remains unknown. The research also raises further questions about what other morphological, physiological, or biological differences between the two bed bug species may be relevant for control methods.

Kim D-Y., Billen J., Doggett S.L., Lee C-Y. (2017). Differences in climbing ability of *Cimex lectularius* and *Cimex hemipterus* (Hemiptera: Cimicidae). *Journal of Economic Entomology*, 110: 1179-1186.

Advances in the Biology and Management of Modern Bed Bugs was the first comprehensive academic text on bed bugs for 50 years. Pictured are the editors, Stephen Doggett, Dini Miller and Chow-Yang Lee.

2017: Practical Advice for Pitfall Trap Use

Much of the information published on pitfall traps has focused on their use in research with large quantities of the devices, offering limited practical guidance for pest managers in the field. Addressing this gap, researchers from the University of Tennessee set out to determine the minimum number of pitfall traps required to detect low-level bed bug activity in low-income apartments. They discovered that using just two monitors was sufficient to detect most infestations, with the crucial factor being the placement of monitors adjacent to the bed. This finding provides a more cost-effective approach to using bed bug monitors in pest management.

Vail K.M., Chandler J.G. (2017). Bed bug (Hemiptera: Cimicidae) detection in low-income, high-rise apartments using four or fewer passive monitors. *Journal of Economic Entomology*, 110: 1187–1194.

2017: How do Bed Bugs Respond to Insecticide Dusts?

Many laboratory trials testing insecticides involve placing insects directly onto treated surfaces in a 'no-choice' or 'forced exposure' setup. However, this may not accurately reflect field conditions, where insects might avoid treated areas. This was observed in trials comparing diatomaceous earth dust (DED) with pyrethroid and silica-based dusts. Bed bugs showed a tendency to avoid DED, indicating it might be a less effective option for field use. Further research by other scientists (referenced in 2023) supported this, finding that bed bugs were not effectively controlled in DED-treated harbourages.

The work of Agnew and Romero highlights a key point: while forced exposure tests can demonstrate efficacy, real-world effectiveness may be compromised if bed bugs naturally

avoid treated surfaces. This underscores the importance of considering insect behaviour in field situations where they have the option to traverse treated areas.

Agnew J.L., Romero A. (2017). Behavioral responses of the common bed bug, *Cimex lectularius*, to insecticide dusts. *Insects*, 8: 83.

2018: First Academic Text in over 50 Years

During the modern global resurgence of bed bugs, several practical management-focused texts were published. However, the last academic book on this subject, "*The Monograph of the Cimicidae*" by Robert Usinger, was released back in 1966. Addressing this gap, "*Advances in the Biology and Management of Modern Bed Bugs*," edited by Stephen Doggett, Dini Miller, and Chow-Yang Lee, was aimed at providing a comprehensive update on the contemporary science of bed bugs. This volume included 46 chapters contributed by 60 experts, covering a wide range of topics such as the epidemiology of bed bugs, their health impacts, biology, management techniques, and legal issues. Unfortunately, the high price set by the publishing house made this important text unaffordable for many.

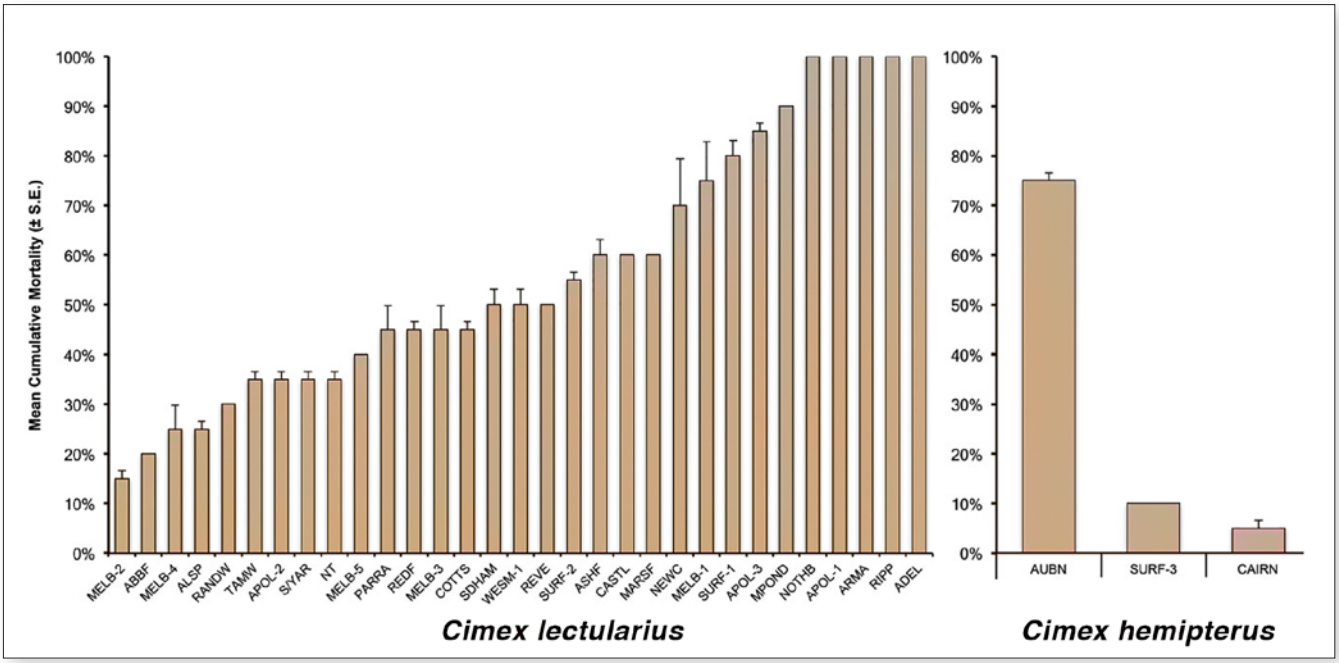
Doggett S.L., Miller D.M., Lee C.Y. (2018). Advances in the Biology and Management of Modern Bed Bugs. *Wiley Blackwell, Oxford, UK*.

2018: Random Control Failures Explained

During his PhD research, David Lilly collected multiple strains of *Cimex lectularius* and *Cimex hemipterus* from across Australia and exposed them to deltamethrin at a concentration 10 times the recommended label rate. He evaluated some 35 strains, observing a tremendous variation in efficacy. In some strains, all bed bugs died, while in others, very few were killed. This finding helps to explain the inconsistent effectiveness observed in field situations and underscores the importance of conducting post-treatment evaluations.

David's research also showed that *Cimex hemipterus* strains with 'super-*kdr*' mutations were the most challenging to exterminate using pyrethroids. Additionally, his work indicated that imidacloprid had excellent topical efficacy against all strains of bed bugs, although its residual effectiveness was limited.

Lilly D., Dang K., Webb C. and Doggett S. L. (2018). Are Australian field-collected strains of *Cimex lectularius* and *Cimex hemipterus* (Hemiptera:



In 2018, David Lilly and colleagues exposed 35 field strains of *Cimex lectularius* and 3 field strains of *Cimex hemipterus* to 10x the label rate of deltamethrin and showed the enourmous variability in efficacy that can be observed. The also demonstrated that the tropical species is much more difficult to kill.

Cimicidae) resistant to deltamethrin and imidacloprid as revealed by topical assay? *Austral Entomology*, 57: 77-84.

2020: COVID-19 Outbreak

The lockdowns and travel bans during the Coronavirus Disease 2019 (COVID-19) pandemic significantly reduced opportunities for people to acquire bed bugs or transmit them to others. As a result, bed bug infestations decreased during this period. Anecdotal evidence suggests that infestation rates fell by 30-50%, although there is no concrete data available to quantify this reduction precisely.

2021: Bed Bugs the Cause of a Malaria Increase?

Research conducted in Ghana, a region in Africa endemic to malaria, revealed that long-lasting insecticidal nets (LLINs), designed to prevent mosquito bites and reduce malaria incidence, were ineffective in controlling field bed bug infestations. Residents reported that bed bugs often used the nets as hiding places. The nuisance of bed bug bites led to lower compliance in using these nets. There has been a recent increase in malaria cases in Africa, and it's plausible that this uptick is partly due to the reduced use of LLINs because of bed bugs. Intriguingly, a 2023 survey on community attitudes found that many participants believed that the bed nets provided by the government were infested with bed bugs!

Deku G., Combey R., Doggett S.L. (2021). Assessment of tropical bed bug (Hemiptera: Cimicidae), infestations in Cape Coast, Ghana: household control practices and efficacy of commercial insecticides and long-lasting insecticidal nets against field bed bugs. *Journal of Medical Entomology*, 58: 1788–1797.

2023: International Consortium Test Controversial Product

Some products on the market are highly controversial, especially those that rely on pyrethroids to work in the face of widespread pyrethroid resistance. One example is permethrin impregnated encasements. Initial tests conducted by Stephen Doggett in 2011 on one such product, the ActiveGuard mattress encasement, demonstrated poor efficacy even with constant exposure over 16 days. Subsequently, a study funded by the manufacturer produced results suggesting a high degree of efficacy on several bed bug strains (Jones *et al*. 2013), although many researchers remained sceptical of the product due to the wide reports of insecticide resistance. To investigate this product more thoroughly and independently, an international consortium was established. Some 24 bed bug strains collected from disparate parts of the globe, including a mix of tropical and common species, were used to evaluate the efficacy of the ActiveGuard. While the more susceptible strains of bed bugs died, most of the field strains showed little to even no mortality. The authors concluded that "permethrin-impregnated mattress liners should not be recommended as part of an overall bed bug management program." Extensive multi-national cooperation such as in this study is a powerful means of evaluating products.

Jones S.C., Bryant J.L., Harrison S.A. (2013). Behavioral responses of the bed bug to permethrin-impregnated ActiveGuard(TM) fabric. *Insects*, 4: 230-240.

Leong X-Y., Lee C-Y., Veera Singham G., Shu-Chien A.C., Naylor R., Naylor A., Miller D.M., Wilson M.M., Lilly D.G., Doggett S.L. (2023). Evaluation of a pyrethroid-impregnated mattress liner for controlling multiple international strains of *Cimex lectularius* and *Cimex hemipterus*. *Journal of Economic Entomology*, 116: 19-28.

2023: Lethal Harbourage Trap

Bed bug management can be costly, primarily due to the challenges posed by insecticide resistance. To find more cost-effective control solutions, researchers explored the concept of 'lethal harbourages.' Essentially, cardboard pieces were treated with silica dioxide (ChinCheX) and then provided to bed bugs as potential harbourage sites in a laboratory setting. The results were remarkable, as all the bed bugs exposed to these treated harbourages died.

The idea behind this approach is that if harbourages around a bed can be minimized through strategies such as sealing cracks and

In late 2023, the media expoded with widespread reports of bed bugs in Paris. This frenzy spread to other nations, with increased reports of bed bugs coming from Hong Kong, Korea, and Singapore.

crevices and using mattress encasements (as suggested by Richard Naylor's 2012 work mentioned earlier), harbourage traps might be effective at controlling an infestation and even preventing one from becoming established. However, it's important to note that field trials are needed to validate this concept. Nevertheless, lethal harbourages show great promise and have the advantage of being extremely cost-effective to produce.

Kerdsawang J., Dang K., Chareonviriyaphap T., Doggett S.L. (2023). Laboratory Insecticide efficacy trials of lethal harborages for control of the common bed bug, *Cimex lectularius* (Hemiptera: Cimicidae). *Insects*, 14: 814.

2023: Paris Media Explosion!

In October 2023, the global media went into a frenzy over reports of bed bugs in Paris, France. This coincided with Paris Fashion Week and the Rugby World Cup, placing Paris in the international spotlight, especially in the year leading up to the Olympics. Social media influencers drew attention to the issue, sharing videos that showed bed bugs on trains in Paris. This surge in coverage followed a recent report indicating that 13% of rooms in homeless shelters in France were infested with bed bugs (Hasnaoui *et al*. 2023). The media frenzy quickly spread worldwide, with reporters repeatedly asking the same question: "*Will the bed bugs from Paris spread to my country?*" It's important to note that the insects in Paris are the same as those found elsewhere!

Other countries also reported increased bed bug activity. In Ireland, it was claimed in early November that bed bug numbers were six times higher than usual. In Seoul, at least 17 outbreaks of bed bugs were reported, although this may not seem like a large number. This raises the question of whether this is merely media hype or a genuine issue. Only time will provide the answer.

Hasnaoui B., Bérenger J. M., Delaunay P., Diarra A. Z., Ndiaye E. H. I., M'madi S. A., et al. (2023). Survey of bed bug infestations in homeless shelters in southern France. *Scientific Reports*, 13: 12557.

25 Years: A Summary

Writing this article presented the great challenge of determining which research and key events to include, given that nearly 955 research papers on bed bugs have been published over the last quarter-century. This does not even count those in trade industry magazines, which could easily double that figure. Nevertheless, there were undeniably critical papers and significant events that shaped the industry during this period. The focus has been on these, though it's likely that others may have a slightly different list.

To summarize the 25 years of the global bed bug resurgence, we can start by noting that it took some time for the resurgence to become widely recognized. The initial paper in 1998 by Birchard, which suggested a resurgence, appeared in an obscure UK medical magazine not read by entomologists. Even early reports in pest control journals were met with scepticism by academics. It wasn't until hard evidence was available and presented at academic conferences by researchers like the authors of this article that research programs began. This delay in recognition, action, and public awareness, allowed bed bugs to establish themselves worldwide.

Resistance to insecticides was quickly identified as the major trigger for the resurgence. Birchard's first paper even hinted at possible resistance as insecticides were becoming ineffective. Since then, much research has focused on this topic, either testing the efficacy of insecticides or investigating the mechanisms behind resistance. Over the years, bed bugs have been shown to develop resistance rapidly to various insecticide classes, and multiple resistance mechanisms have been identified. We can expect more research and reports of resistance in the future.

One noticeable aspect is the limited number of researchers who have worked on bed bugs during these 25 years, with the same names repeatedly appearing. There are valid reasons for this. Bed bugs are challenging to study due to their slow growth, low daily fecundity, and the need for a blood meal at all stages, making them laborious to maintain in the laboratory. Additionally, attracting funding for bed bug research is difficult since they do not transmit disease-causing pathogens like other vector-borne pests. This results in fewer researchers in the field, which in turn leads to lower citation counts for their research.

For instance, in the 10-year period from 2010 to 2019, 570 papers on bed bugs were published, while research on mosquitoes produced 26,884 papers during the same period, almost 50 times as many. Mosquito researchers are likely to receive more citations, grants, and quicker career advancement. This slower pace of research on bed bugs has been a limitation.

Another issue is the scarcity of research on *C. hemipterus*, which is found in densely populated regions and affects more people. Limited research indicates that it is more resistant than *C. lectularius* and has unique adaptations, such as its leg morphology that renders pitfall traps less effective than they are for the common bed bug. Exploring other distinctive features of tropical bed bugs is necessary, but research has been hampered by the absence of susceptible strains for use in insecticide trials. Unfortunately, *C. hemipterus* occurs in regions where vector-borne diseases like malaria and dengue are prevalent, making research even more challenging to fund.

Perhaps the most critical lesson in bed bug management over the past 25 years is one that has remained consistent for 2,500 years. Namely, early detection, reduction of harbourage sites, extensive inspection, use of non-chemical methods to reduce insect populations and combat against resistance, thorough and diligent treatments, post-treatment evaluation, and educating all stakeholders in best practices.

Highlights

Notable highlights during this period include the rapid translation of research into action within the pest management industry in the USA. Researchers like Dini Miller, Michael Potter, Richard Cooper, and Changlu Wang have played pivotal roles by sharing their research at pest management events and contributing to industry publications. Unfortunately, few

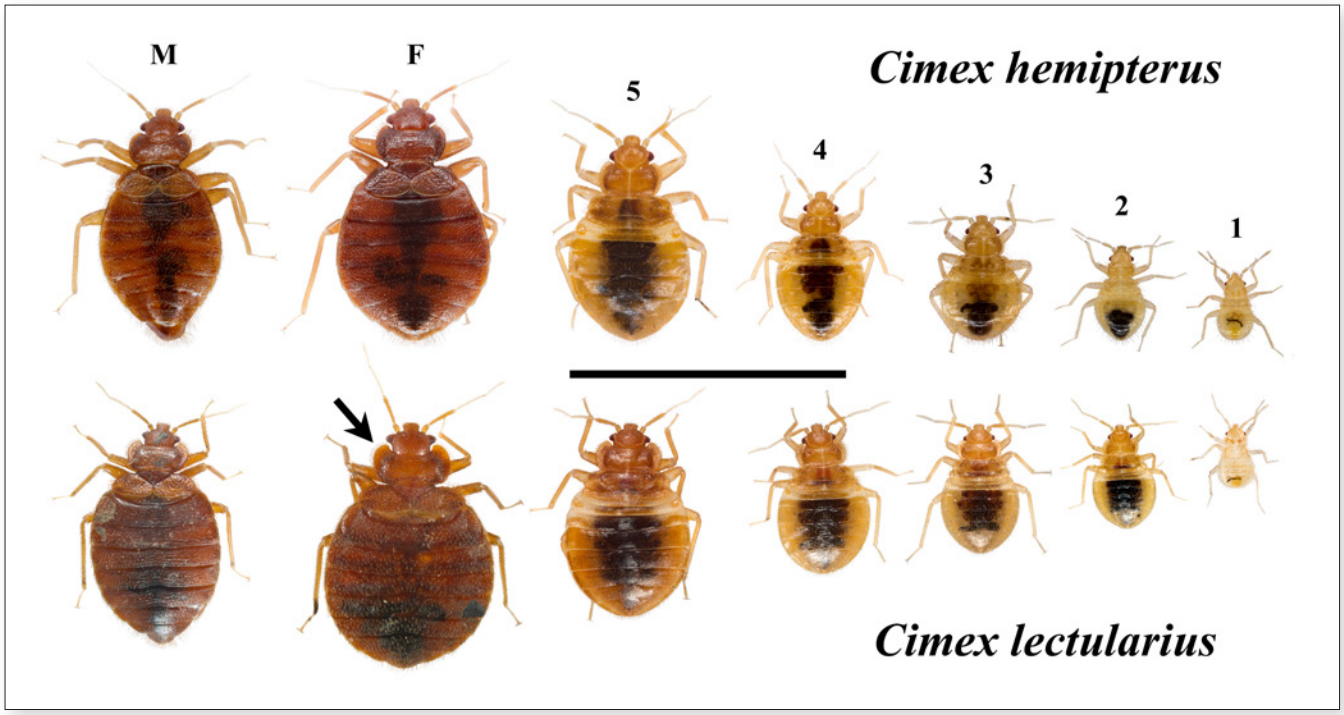
active pest managers read scientific journals or pest management periodicals outside of their own region. Thus, getting the latest knowledge widely accepted, on a global basis is a real challenge.

Responsible pest management associations worldwide have taken positive steps. For instance, the Australian Environmental Pest Management Association (AEPMA) initiated the development of a best practice management document in 2005, just a year after the first publication indicated a bed bug resurgence in Australia. Products to be avoided were even listed in the Australian 'Code of Practice,' which helped prevent questionable products from entering the Australian market. Unfortunately, other associations have not followed suit, and the global pest control industry should unite against subpar products and poor management practices. Alternatively, the academic community may be better positioned in some parts of the world to address this issue, however funding to conduct such studies will be challenging.

Lowlights

What is both surprising and alarming, is how stakeholders most impacted by bed bugs have often ignored the problem. The backpacking industry, hotels and resorts, and low-income housing providers, have all failed to develop best practice documents. This neglect has primarily benefited bed bugs themselves. Sadly, there have been many other failures during the global resurgence.

One of the most significant negative issues has been the proliferation of ineffectual products, as discussed in the 2011 paper. Some products on the market have been backed by venture capital companies, where more money is spent on advertising and promotion than on demonstrating their actual efficacy. Others have simply been sold for quick profit. Researchers have been paid substantial sums of money, sometimes even hundreds of thousands, to produce data supporting questionable products. Some researchers have failed to declare conflicts of interest in their publications, which raises doubts about the integrity of their research. Unfortunately, few researchers, pest management associations, or industry publications are willing to openly criticize ineffective products due to concerns about litigation, potential loss of research funding, or advertising revenue. Consequently, these products continue to be on the market, often being sold to low-income housing residents, disproportionately affecting the poor and vulnerable in society.



In an ideal world, a research group would be established to comprehensively test all the products on the market to determine their effectiveness and limitations of use. Unfortunately, this remains unlikely to happen.

We now understand that poor pest management was a major contributor to the extent of the resurgence and the rapid proliferation of bed bugs. Unfortunately, subpar pest control practices persist. Despite the numerous articles (in both peer-reviewed and trade journals) demonstrating the effectiveness of various non-chemical methods -reviewed and importance of integrating these methods into bed bug management programs, there continues to be a reliance on pesticides, which are inexpensive and easy to apply. For example, in the USA, surveys of pest management professionals reveal that most companies (greater than 97%) utilize pesticides to control bed bugs, while fewer than 50% use effective methods like vacuums and steam. Such poor choices in bed bug management can lead to uncontrolled infestations, chronically infested living communities, further spread throughout society, and promote the continued development of resistance.

Poor understanding of effective bed bug management can have dire consequences, as people become desperate to control infestations and resort to extreme measures. In some cases, this has resulted in fatalities, as exemplified by the somewhat regular reports of illicit use of phosphine tablets leading to tragic outcomes. Unfortunately, phosphine tablets can readily be purchased over the internet, and many nations do not sufficiently regulate their use.

Over the past 25 years, a notable failure was the attempt by the US Environmental Protection Agency (USEPA) to develop standardized testing procedures for evaluating insecticide efficacy. The result was a document prescribing a testing algorithm that was both impractical and nearly impossible to adhere to. Moreover, its definition of resistance overlooked existing published information. In late 2022, the Organisation for Economic Co-operation and Development issued a more practical guideline for insecticide efficacy testing (https://tinyurl.com/y4mn3epn). However, this guideline is still far from perfect and urgently needs input from active bed bug researchers. The challenge of any testing procedure lies in the significant variation among bed bugs. Different strains exhibit diverse resistance mechanisms, leading to substantial differences in efficacy during insecticide testing or application (as highlighted by the 2018 paper by Lilly and colleagues). Both guidelines do not adequately address the tropical bed bug, as it is crucial to conduct efficacy testing on strains of this species that possess the super-*kdr* trait.

In the book "*Advances in the Biology and Management of Modern Bed Bugs*," the quote at the start of the chapter was, "*It is extraordinary to think we are yet to define what the bed bug problem is*." This reflects the extraordinary challenge of defining the bed bug problem over the past 25 years. We still lack a comprehensive understanding of the extent of the resurgence, which groups are affected, and the economic costs inflicted by these insects on society. Epidemiological data on infestations worldwide is virtually non-existent. Without this crucial information, we often find ourselves working in the dark. Considering the reluctance of all stakeholders to report infestations, the situation is unlikely to change in the next 25 years.

The Next 25 Years?

So, what does the future hold for the next 25 years, and more importantly, will we witness a decline in bed bug populations?

The first 25 years did see some significant additions to the market in the form of several highly effective non-chemical methods, more effective detection and monitoring techniques, and more effective insecticides, particularly the dual-action products, silica dioxide, and the biopesticide Aprehend. While the latter product requires further evaluation of its effectiveness in hotter climates, there is no doubt that we are in a much better position than we were back in 1998. Those highly experienced in bed bug control would rightly argue that these options are sufficient to manage any bed bug infestation. However, none of these products can be applied as a single quick solution, making bed bug control labour-intensive, costly, and often beyond the financial means of many.

One promising active ingredient is broflanilide, a new class of insecticide developed by Mitsui in Japan. Various publications have demonstrated its high efficacy in controlling multi-resistant strains of mosquitoes. Unpublished work conducted by Kai Dang in Stephen Doggett's lab shows promising results as the chemical can effectively eliminate resistant bed bug

strains and has ovicidal activity. BASF holds the commercial rights for the product in the urban pest control industry and received approval for its registration in Australia back in 2019 under the label "Vedira" for bed bug management. However, the company has not yet brought the product to market, and it remains unclear when or if they will do so.

One major concern with broflanilide is that it belongs to the class of compounds known as "polyfluoroalkyl substances" or, more simply, "PFAS." PFAS compounds have been in the news in recent years due to their extreme stability, mobility in the environment, resistance to natural breakdown, and toxicity to various animals. These factors may prove to be challenges that could prevent the entry of this new and highly effective product in the global marketplace.

Overall, bed bugs represent only a small fraction of the global pest control market. This makes it financially challenging for manufacturers to invest heavily in the development of new insecticides or control products specifically for bed bugs. Therefore, it's difficult to envision the emergence of any highly effective products tailored for bed bug management.

Research on bed bugs will continue to be a challenge for the reasons described above, which means that the number of research papers published over the next 25 years may decline. Perhaps the key focus for the next 25 years should be on targeting more effective bed bug management in low-income housing, as the poor have become the reservoir for bed bugs in wider society. By addressing this issue, we may be able to reverse the bed bug resurgence over the next quarter of a century.

In conclusion, the past 25 years have marked a significant chapter in our ongoing struggle with the bed bug, an adversary as resilient as it is unwelcome. The global resurgence of these pests has been a wake-up call, highlighting not only the adaptability and persistence of *Cimex lectularius* and *Cimex hemipterus,* but also the interconnectedness of our modern world. International travel, changes in pest control practices, insecticide resistance, and a lack of public awareness have all played their roles in facilitating the bed bug's comeback.

The fight against bed bugs is multifaceted, involving entomologists, pest control professionals, public health officials, and an informed public. It is a battle that cannot be won through chemical warfare alone. The integration of pest management strategies—ranging from better detection methods, public education, heat and cold treatments, and newer, more targeted use of insecticides, may well turn the tide, offering hope that we can keep these blood-sucking parasites at bay.

The 25-year saga of the bed bug's resurgence has been a reminder that in the global village of the 21st century, the smallest creatures can have the largest impact on our lives. By continuing to foster collaboration across borders and disciplines, investing in research, and educating the public and all stakeholders, we can ensure that the next 25 years are marked not by a resurgence, but by sustainable management and the prevention of bed bug infestations.

The Key Players

Over the past 25 years, numerous authors have contributed significantly to the study of bed bugs. These individuals, listed below in alphabetical order, have greatly enhanced our understanding of key aspects of pest biology relevant to their management and control. Each has published at least 15 papers on the subject and their number of papers on bed bugs are listed. We sincerely apologize to the many other contributors who are not included in this list.

Warren Booth (USA): Warren, with a background in molecular biology, played a key role in demonstrating that bed bug infestations in chronically infested buildings often begin with a single insect. His research has largely focused on population genetics. Warren has published 22 articles on bed bugs [including book chapters (1), peer-reviewed papers (19), conference proceedings (1), industry magazines (1)].

Clive Boase (UK): Clive was the first globally to provide concrete evidence of the bed bug resurgence and that modern strains were resistant. His research has focused on

Warren Booth

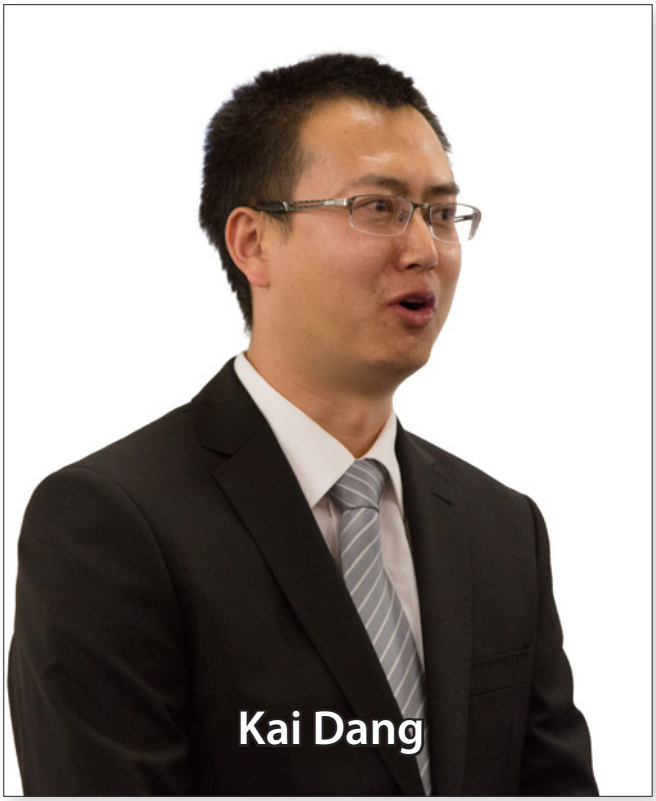
Clive Boase with the 'Okey' bed bug trap

practical aspects of bed bug management. He is also renowned as one of the founders of the International Conference on Urban Pests, a premier event for disseminating the latest knowledge in the field. 20 articles [book chapters (3), peer-reviewed papers (2), conference proceedings (4), industry magazines (11)].

Richard Cooper (USA): Rick has been working in collaboration with Changlu Wang for many years, and has published seminal articles on bed bug dispersal. His work primarily focuses on bed bug detection and management, particularly in low-income housing. Rick is a highly sought-after speaker in the pest management industry. 56 articles [books (2), monographs (2), book chapters (6), peer-reviewed papers (28), industry magazines (19)].

Kai Dang (Australia and Malaysia): Kai has collaborated with both Stephen Doggett's and Chow-Yang Lee's laboratories. His research has focused on elucidating resistance mechanisms in bed bugs and investigating the efficacy of insecticides.18 papers [monographs (1), peer-

Richard (Rick) Cooper



reviewed papers (12), conference proceedings (3), industry magazines (2)].

Stephen Doggett (Australia): Stephen was the first to report the resurgence of bed bugs in Australia and to develop an industry standard. He served as the Chief Editor of the first academic textbook on the subject in 50

years and has conducted extensive research on bed bug management. Lately he has taken a great interest in how bed bugs have influenced popular culture. He has lectured in over 20 countries on bed bugs and is a regular speaker at pest management events.145 articles [books (2), monographs (13), book chapters (14), peer-reviewed papers (38), conference proceedings (13), industry magazines (65)].

Chow-Yang Lee (Malaysia and USA): Chow-Yang, a highly renowned researcher in urban entomology, has recently delved into bed bug research. Many of his papers centre on resistance and the effectiveness of insecticides. Alongside his student Chris Kim, he demonstrated that tropical bed bugs have hairy feet, which enables

them to escape from pitfall traps. 33 articles [books (1), book chapters (5), peer-reviewed papers (23), conference proceedings (1), industry magazines (4)].

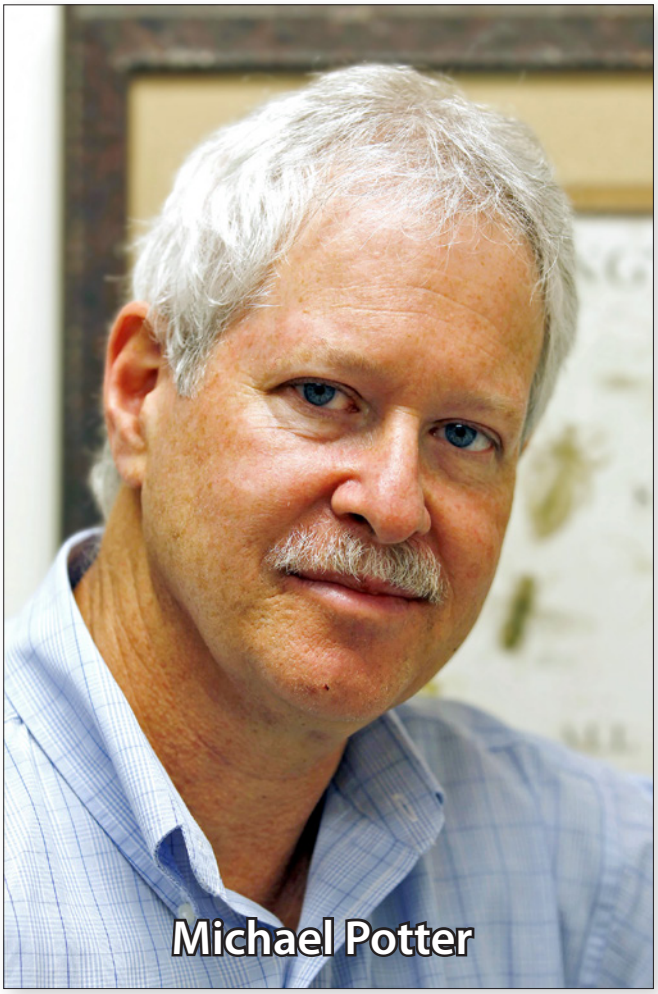
David Lilly (Australia): David completed both a Master's and a PhD focused on bed bugs

in Stephen Doggett's lab. He was the first to show that resistant bed bugs possess a thicker cuticle and that the tropical bed bug species exhibits significantly higher resistance than the common variety. Additionally, he has conducted extensive research on the effectiveness of insecticides. 27 articles [monographs (1), book chapters (3), peer-reviewed papers (11), conference proceedings (3), industry magazines (9)].

Dini Miller (USA): Dini Miller is widely considered one of the most sought-after speakers globally on bed bugs and their control, being renowned for her ability to transform complex research into practical management advice. She has extensively worked in low-income housing, exploring various non-chemical and insecticide-based control solutions. 37 articles [books (1), book chapters (11), peer-reviewed papers (18), conference proceedings (3), industry magazines (4)].

Richard Naylor (UK): Richard is best known for his ground-breaking research on bed bug dispersal as part of his PhD. He has worked on practical solutions for bed bug management, including insecticide efficacy. He built his own unique testing facility, which includes two bedrooms, where bed bug dispersal can

be investigated, as well as the effectiveness of traps. 31 articles [monographs (2), book chapters (3), peer-reviewed papers (20), conference proceedings (3), industry magazines (4)].



Michael Potter (USA): Before retiring, Mike was a well-regarded speaker at pest management events and one of the pioneering researchers in modern bed bugs. He conducted ground-breaking research, notably being the first to explore dual-action insecticides and the use of silica dioxide. His primary focus was on the efficacy of insecticides. Additionally, he was the first to document the history of bed bug management and was a regular contributor to industry magazines. 57 articles [book chapters (2), peer-reviewed papers (18), conference proceedings (4), industry magazines (33)].

Alvaro Romero (USA): Having collaborated extensively with Mike Potter, Alvaro was the first to publish research on insecticide resistance in the United States, including findings on

neonicotinoid resistance. The majority of his research has focused on the efficacy of insecticides. 34 articles [book chapters (1), peer-reviewed papers (19), conference proceedings (1), industry magazines (13)].

Narinderpal Singh (USA): Narinderpal has been a key member of the Changlu Wang/Rick Cooper team. His research primarily focuses on monitoring and controlling bed bugs using insecticides. 23 articles [peer-reviewed papers (20), industry magazines (3)].

Changlu Wang (USA): Changlu Wang has led a team of highly active researchers at Rutgers University. He was the pioneer in testing pitfall traps and using them to study the dynamics and dispersal of bed bug infestations. His extensive research has focused on investigating and advocating Integrated Pest Management (IPM), particularly in low-income housing. This work has involved exploring practical non-chemical and insecticide-based management solutions. 77 articles [book chapters (4), peer-reviewed papers (62), industry magazines (11)].

Final thought. In 2007, Stephen Doggett shared images with Rick Cooper for inclusion in the Bed Bug Handbook. In appreciation, Rick sent a complimentary copy to Stephen, expressing his gratitude with these words: "*Thank you very much for your contribution to our book. Bed bugs, who would have ever thought! From one bedbugger to another, enjoy the ride.*" And a ride it has been!. ■

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