

Contents

List of Contributors *xix*

Foreword *xxiii*

Acknowledgments *xxv*

Introduction *1*

Stephen L. Doggett, Dini M. Miller and Chow-Yang Lee

Part I Bed Bugs in Society *7*

1 Bed Bugs Through History *9*

Michael F. Potter

- 1.1 Introduction *9*
- 1.2 Origins and Spread *9*
- 1.3 Early Extermination Methods *11*
- 1.4 Propagation Within Cities (1880s–1950s) *13*
- 1.5 Determination – and a Silver Bullet *15*
- 1.5.1 Bed Bug Insecticides *16*
- 1.5.2 Bug Proof Design and Construction *21*
- 1.5.3 Bed Bug Traps *21*
- 1.5.4 Lethal Temperatures *21*
- 1.6 Past is Present *23*
- References *23*

2 Bed Bugs in Popular Culture *27*

Stephen L. Doggett and David Cain

- 2.1 Introduction *27*
- 2.2 Bed Bugs in Poetry *27*
- 2.3 Bed Bugs in the Figurative Arts *28*
- 2.4 Bed Bugs in Theatre *30*
- 2.5 Bed Bugs in Literature *32*
- 2.6 Bed Bugs in Music *34*
- 2.7 Bed Bugs in Television *35*
- 2.8 Bed Bugs in Linguistics *36*
- 2.9 Bed Bugs in Erotica *37*
- 2.10 The Use of Bed Bugs in Popular Culture Through Time *37*
- References *38*

Part II The Global Bed Bug Resurgence 43**3 The Bed Bug Resurgence in North America 45***Dini M. Miller*

- 3.1 Introduction 45
- 3.2 Bed Bug Resurgence in the United States 45
- 3.3 Bed Bug Resurgence in Canada 46
- 3.4 Summary 48
- References 48

4 The Bed Bug Resurgence in Latin America 51*Roberto M. Pereira, Ana Eugenia de Carvalho Campos, Joao Justi (Jr.) and Márcio R. Lage*

- 4.1 Introduction 51
- 4.2 Bed Bugs in Brazil 51
- 4.3 The Resurgence of Bed Bugs in Brazil 53
- 4.4 Elsewhere in Latin America 55
- References 56

5 The Bed Bug Resurgence in Europe and Russia 59*Richard Naylor, Ondřej Balvín, Pascal Delaunay, and Mohammad Akhoundi*

- 5.1 Introduction 59
- 5.2 History of Bed Bugs in the Region 59
- 5.3 Historical Laws to Control Bed Bugs Pre-resurgence 60
- 5.4 Documented Evidence for the Bed Bug Decline 61
- 5.5 Early Evidence for the Resurgence 62
- 5.6 The Degree of the Resurgence 63
- 5.7 Region-specific Factors in the Resurgence 64
- 5.8 Strategies to Combat the Resurgence 65
- References 66

6 The Bed Bug Resurgence in Asia 69*Chow-Yang Lee, Motokazu Hirao, Changlu Wang, and Yijuan Xu*

- 6.1 Introduction 69
- 6.2 History of Bed Bugs in Asia 69
- 6.3 Laws, Regulations and Policies for Bed Bug Control Prior to the Resurgence 70
- 6.4 Modern Resurgence of Bed Bugs in Asia 71
- 6.5 Specific Factors Related to the Bed Bug Resurgence in Asia 73
- 6.6 Bed Bug Management Strategies in Asia 74
- References 76

7 The Bed Bug Resurgence in Australia 81*Stephen L. Doggett and Toni Cains*

- 7.1 Introduction 81
- 7.2 History of Bed Bugs in Australia 81
- 7.3 Documented Evidence for the Bed Bug Decline 82
- 7.4 The Modern Resurgence 83
- 7.5 Strategies to Combat the Bed Bug Resurgence 84
- References 85

8	The Bed Bug Resurgence in Africa	87
	<i>Josephus Fourie and Dionne Crafford</i>	
8.1	Introduction	87
8.2	History of Bed Bugs in Africa	87
8.3	Laws, Regulations, and Policies for Bed Bug Control Pre-resurgence	88
8.4	Documented Evidence for the Bed Bug Decline	88
8.5	Early Evidence for the Resurgence	89
8.6	The Extent of the Resurgence	89
8.7	Region- and Country-specific Reasons for the Resurgence	91
8.8	Strategies to Combat the Resurgence and Relative Success	92
	References	93
9	The Bed Bug Resurgence in the Indian Subcontinent	95
	<i>Anil S. Rao and Joshua A. Rao</i>	
9.1	Introduction	95
9.2	History of Bed Bugs in the Indian Subcontinent	95
9.3	Laws to Control Bed Bugs Pre-resurgence	96
9.4	Documented Evidence for the Bed Bug Decline	96
9.5	The Modern Resurgence	96
9.6	Strategies to Combat the Bed Bug Resurgence	97
	References	98
10	The Bed Bug Resurgence in the Middle East	101
	<i>Odelon Del Mundo Reyes</i>	
10.1	Introduction	101
10.2	History of Bed Bugs in The Middle East	101
10.3	Regional Reports of the Bed Bug Resurgence	102
10.4	Impact of the Bed Bug Resurgence	103
10.5	Pest Management Professionals Close Encounters with Cimicids	103
	References	104
	Part III Bed Bug Impacts	107
11	Dermatology and Immunology	109
	<i>Shelley Ji Eun Hwang, Stephen L. Boggett and Pablo Fernandez-Penas</i>	
11.1	Introduction	109
11.2	Bed Bug Saliva	109
11.3	Cutaneous Reactions	110
11.4	Dermatological Complications from Bed Bug Bites	111
11.5	Systemic Reactions	112
11.6	Immunological and Pathogenic Mechanisms	112
11.7	Dermatopathology	112
11.8	Differential Diagnoses of Bed Bug Bites	113
11.9	Clinical Management	114
11.10	Conclusion	114
	References	114

12	Bed Bugs and Infectious Diseases	117
	<i>Stephen L. Doggett</i>	
12.1	Introduction	117
12.2	Vectors and Transmission Pathways	117
12.3	Bed Bugs and Infectious Diseases: an Overview	118
12.4	Why do Bed Bugs not Transmit Infectious Diseases?	120
12.5	The Future Hunt for Pathogens: A Cautionary Note	121
12.6	Conclusion	122
	References	122
13	Mental Health Impacts	127
	<i>Stéphane Perron, Geneviève Hamelin and David Kaiser</i>	
13.1	Introduction	127
13.2	Methods	127
13.3	Main Findings	129
13.4	What Can Be Inferred from the Current State of the Literature?	130
13.5	Limitations and Future Research	130
13.6	Conclusion	131
	References	131
14	Miscellaneous Health Impacts	133
	<i>Stephen L. Doggett</i>	
14.1	Introduction	133
14.2	Respiratory Issues	133
14.3	Blood Loss	134
14.4	Sleep Loss	134
14.5	Chemical Exposure	135
14.6	Miscellaneous Health Impacts	135
	References	136
15	Fiscal Impacts	139
	<i>Stephen L. Doggett, Dini M. Miller, Karen Vail and Molly S. Wilson</i>	
15.1	Introduction	139
15.2	Types of Cost	139
15.3	Costs to the Multi-Unit Housing Industry	140
15.4	Cost to the Hospitality and Travel Industry	142
15.5	Cost to the Retail Industry	143
15.6	Brand Damage in the Housing, Hospitality, and Retail Industries	143
15.7	Legal Expenses	144
15.8	Cost to Pest Management Companies	144
15.9	Bed Bug Management Revenues	145
15.10	Conclusions	145
	References	146
	Part IV Bed Bug Biology	149
16	Bed Bug Biology	151
	<i>Sophie E.F. Evison, William T. Hentley, Rebecca Wilson, and Michael T. Siva-Jothy</i>	
16.1	Introduction	151
16.2	Hematophagy	151

16.3	Anachoresis	152
16.4	Flightlessness	153
16.5	Reproduction	153
16.6	Egg Laying	155
16.7	Host-seeking Behavior	155
16.8	Harborage Seeking Behavior and Aggregation	156
16.9	Dispersal	156
	References	158
17	Chemical Ecology	163
	<i>Gerhard Gries</i>	
17.1	Introduction	163
17.2	Olfaction and Contact Chemoreception	163
17.2.1	General Introduction	163
17.2.2	Olfactory Sensilla on Bed Bug Antennae and their Responses to Odorants	164
17.2.3	Molecular Mechanisms Underlying Olfaction	164
17.3	Pheromones	165
17.3.1	Alarm Pheromone	165
17.3.2	Aggregation Pheromone	165
17.3.3	Sex-attractant Pheromone	168
17.3.4	Anti-mating and Anti-aphrodisiac Pheromones	168
17.4	Host Seeking	169
	References	170
18	Population Genetics	173
	<i>Warren Booth, Coby Schal and Edward L. Vargo</i>	
18.1	Introduction	173
18.2	The Evolution of Modern Bed Bugs	173
18.3	Genetic Variation Within Populations	174
18.4	Genetic Variation Among Populations	175
18.5	Mitochondrial Heteroplasmy	177
18.5.1	Variation in Heteroplasmy Across Host Lineages and Among Populations	178
18.5.2	Implications of Heteroplasmy	179
18.5.3	Insecticide Resistance, <i>kdr</i> , and Geographic Variation	179
18.6	Future Directions in Bed Bug Population Genetics	180
	References	180
19	Physiology	183
	<i>Joshua B. Benoit</i>	
19.1	Introduction	183
19.2	Stress Tolerance and Starvation Resistance	183
19.3	Blood Feeding	187
19.4	Reproduction and Development	187
19.5	Summary and Future Directions	187
	References	188
20	Symbionts	193
	<i>Mark Goodman</i>	
20.1	Introduction	193
20.2	Identity of Endosymbionts	193

20.3	Impact of Symbionts on Bed Bug Biology	194
20.4	Transmission of Symbionts	195
20.5	Symbionts and Bed Bug Management	195
	References	195
21	Bed Bug Laboratory Maintenance	199
	<i>Mark F. Feldlaufer, Linda-Lou O'Connor and Kevin R. Ulrich</i>	
21.1	Introduction	199
21.2	General Colony Maintenance	199
21.2.1	Containers and Harborage	199
21.3	Feeding Techniques	200
21.3.1	<i>In-vivo</i> and <i>In-vitro</i> Blood Sources	200
21.3.2	<i>In-vitro</i> feeding units	202
21.4	Need for Plasma	203
21.5	Development of an Artificial Blood Source	204
	References	204
	Part V Bed Bug Management	209
22	Bed Bug Industry Standards: Australia	211
	<i>Stephen L. Doggett</i>	
22.1	Introduction	211
22.2	Why was the Code Required?	211
22.3	The History and Aims of the Code	211
22.4	The Key Elements of the Code	212
22.5	The Benefits of the Code	213
	References	214
23	Bed Bug Industry Standards: Europe	217
	<i>Richard Naylor</i>	
23.1	Introduction	217
23.2	Why was the Code Required?	217
23.3	The History and Aims of the Code	218
23.4	The Benefits of the Code	219
	References	220
24	Bed Bug Industry Standards: USA	221
	<i>Jim Fredericks</i>	
24.1	Introduction	221
24.2	History and Development of the NPMA Best Management Practices for Bed Bugs	221
24.3	Target Audience	221
24.4	Key Elements of the NPMA Best Management Practices	222
24.5	Marketing and Adoption of the NPMA Best Management Practices	223
24.6	Acceptance of the BMP	223
	References	224

25	A Pest Control Company Perspective	225
	<i>Joelle F. Olson, Mark W. Williams and David G. Lilly</i>	
25.1	Introduction	225
25.2	The Resurgence	225
25.2.1	Rapid and Sustainable Growth	225
25.2.2	Lack of Industry Preparedness	225
25.2.3	Lack of Public Awareness	226
25.3	Responsibility and Liability	226
25.3.1	Educating the Client	226
25.3.2	Liability for Services	227
25.3.3	Financial Burden	227
25.4	Inspection and Control Methods	228
25.4.1	Inspection and Monitoring Tools	228
25.4.2	Chemical Applications and Resistance	228
25.4.3	Non-chemical Applications	229
25.4.4	Training and Maintaining Service Consistency	229
25.5	Conclusion	230
	References	230
26	Prevention	233
	<i>Molly S. Wilson</i>	
26.1	Introduction	233
26.2	Education	234
26.3	Monitors	234
26.4	Mattress Encasements	235
26.5	Desiccant Dusts	236
26.6	Heat	236
26.6.1	Clothes Dryers	237
26.6.2	Heat Chambers	237
26.7	Bed Bug Management Policy	237
	References	238
27	Detection and Monitoring	241
	<i>Richard Cooper and Changlu Wang</i>	
27.1	Importance of Detection and Monitoring	241
27.2	Detection of Bed Bugs	241
27.2.1	Resident Interviews or Surveys	242
27.2.2	Visual Inspection	242
27.2.3	Canine Scent Detection	243
27.2.4	Bed Bug Monitors	244
	Passive Monitors	247
	Active Monitors	248
27.3	Field Comparison of Detection Methods	249
27.4	Bed Bug Inspections	250
27.4.1	Detection	250
	Proactive inspections	251
	Reactive inspections	252

27.4.2	Inspections to Guide and Evaluate Treatment	252
27.4.3	Inspections to Determine Elimination	252
27.4.4	Inspections in Non-traditional Settings	253
	Conflict of Interest Statement	253
	References	254
28	Non-chemical Control	257
	<i>Stephen A. Kells</i>	
28.1	Introduction	257
28.2	Excluding Bed Bugs	258
28.3	Physically Removing Bed Bugs	259
28.4	Creating Adverse Environmental Conditions against Bed Bugs	261
28.4.1	Basic Conditions Causing Lethality	261
28.4.2	Basic Conditions for High-temperature Control	261
	Equipment for Delivery of High Temperatures through Steam Applications	262
	Equipment for Delivery of High Temperatures through Dry Heat Applications	263
	Basic Conditions for Delivery of Low-temperature Treatments	266
	Considerations for Delivery of Low Temperatures	267
28.5	Biological Agents Tested Against Bed Bugs	268
28.6	Other Non-Chemical Control Methods	268
28.7	Conclusion	269
	References	269
29	Insecticide Resistance	273
	<i>Alvaro Romero</i>	
29.1	Introduction	273
29.2	Insecticides and Insecticide Resistance in Bed Bugs	275
29.3	Metabolic Resistance	276
29.4	Reduced Penetration Resistance	277
29.5	Target-site Resistance	277
29.6	Evolution of Resistance and Fitness Costs	279
29.7	Conclusions	279
	References	280
30	Chemical Control	285
	<i>Chow-Yang Lee, Dini M. Miller and Stephen L. Doggett</i>	
30.1	Introduction	285
30.2	Insecticide Classes used Against Bed Bugs	285
30.2.1	Pyrethroids	285
30.2.2	Organophosphates and Carbamates	298
30.2.3	Neonicotinoids	298
30.2.4	Halogenated Pyrroles	299
30.2.5	Insect Growth Regulators	299
30.2.6	Inorganic and Mineral Compounds	299
30.2.7	Botanical Insecticides	300
30.2.8	Poisonous Gases	300
30.3	Insecticide Formulations for Bed Bug Management	300
30.3.1	Liquid Sprays	300
30.3.2	Pressurized Aerosols	301
30.3.3	Dusts	301

- 30.3.4 Fumigants 301
- 30.3.5 Permethrin-impregnated Fabrics 302
- 30.3.6 Insect Repellents 302
- 30.3.7 Total Release Foggers 302
- 30.4 Factors Affecting Insecticide Efficacy 302
- 30.4.1 Test Method 303
- 30.4.2 Test Substrate 303
- 30.4.3 Test Arena 303
- 30.4.4 Experimental Details 303
- 30.4.5 Strain and Bed Bug Species 304
- Susceptible, Resistant, or Both Strains 304
- References 305

31 Limitations of Bed Bug Management Technologies 311

Stephen L. Doggett and Mark F. Feldlaufer

- 31.1 Introduction 311
- 31.2 Bed Bug Detection 311
- 31.2.1 Traps 311
- 31.2.2 Canines 312
- 31.2.3 Novel Detection Methods 313
- 31.3 Bed Bug Control 313
- 31.3.1 Housing Types 313
- 31.3.2 Chemical Control Methods 313
- 31.3.3 Other Chemical Control Products 315
- 31.3.4 Non-chemical Bed Bug Control Methods 316
- 31.3.5 Heat 316
- 31.3.6 Other Non-chemical Controls 316
- References 317

32 Bed Bug Education 323

Jody Gangloff-Kaufmann, Allison Taisey Allen and Dini M. Miller

- 32.1 Introduction 323
- 32.2 Strategies and Successes in Bed Bug Education 323
- 32.3 Educational Programs Focusing on Bed Bugs 324
- 32.4 The Media 326
- 32.5 The Effect of Social Media on Bed Bug Education 327
- 32.6 Identifying the Target Audience 327
- 32.7 Effective Adult Education 327
- 32.8 Measuring the Impacts of Bed Bug Education 328
- 32.9 Conclusion 328
- References 329

Part VI Bed Bug Control in Specific Situations 331

33 Low-income Housing 333

Richard Cooper and Changlu Wang

- 33.1 Introduction 333
- 33.2 Management of Bed Bugs in Low-income Housing 334
- 33.3 Components of a Successful Building- or Complex-wide IPM Program 334

33.3.1	Education	334
33.3.2	Identification of Apartments with Existing Bed Bug Activity	335
33.3.3	Preparation of Apartments for Treatment	336
33.3.4	Treatment of Apartments with Bed Bug Activity	336
33.3.5	Follow-up Service Visits	336
33.3.6	Contracts and the Role of Property Management	337
33.4	The Future	337
	References	338
34	Multi-Unit Housing	341
	<i>Dini M. Miller</i>	
34.1	Introduction	341
34.2	Challenges Unique to the Human Living Environment	341
34.3	Obstructions to Control Success	342
34.3.1	Challenges Unique to Multi-unit Housing	342
34.3.2	Human Host Behavior	342
34.3.3	Financial Limitations for Multi-unit Housing Managers and Owners	342
34.3.4	Pest Management Limitations	343
34.4	Future Prospects for Success	344
	References	345
35	Shelters	347
	<i>Molly S. Wilson</i>	
35.1	Introduction	347
35.2	Challenges in Shelters	347
35.3	Obstacles to Successful Control	348
35.4	Methods of Control in Shelters	348
35.5	Key Elements to Successful Control	349
	References	349
36	Hotels	351
	<i>David Cain</i>	
36.1	Introduction	351
36.2	Bed Bugs in Hotels: The Challenges	351
36.3	Successful Bed Bug Management in Hotels	352
	References	354
37	Healthcare Facilities	357
	<i>Stephen L. Doggett</i>	
37.1	Introduction	357
37.2	The Challenges Bed Bugs Pose to Healthcare Facilities	357
37.3	The History of Bed Bugs in Healthcare Facilities	358
37.4	Bed Bugs in Healthcare Facilities with the Modern Resurgence	358
37.5	Bed Bug Management in Healthcare Facilities	359
	References	360
38	Aircraft	363
	<i>Adam Juson and Catherine Juson</i>	
38.1	Introduction	363
38.2	Aviation Entomology – a Brief History	363

- 38.3 Bed Bug Management on Aircraft: The Challenges 364
- 38.4 Bed Bug Management on Aircraft 365
- 38.5 Improving the Pest Management Protocol 365
- References 366

39 Cruise Ships and Trains 369

David G. Lilly and Garry Jones

- 39.1 Introduction 369
- 39.2 Cruise Ships and Ferries 369
- 39.3 Trains 371
- 39.4 Conclusion 372
- References 373

40 Poultry Industry 375

Allen Szalanski

- 40.1 History – Cimicids and Poultry 375
- 40.2 Mexican Chicken Bug, *Haematosiphon inodorus* 375
- 40.3 Brazilian Chicken Bug, *Ornithocoris toledo* 376
- 40.4 Tropical Bed Bug, *Cimex hemipterus* 376
- 40.5 The Common Bed Bug, *Cimex lectularius* 377
- 40.6 Biology and Impact of *Cimex lectularius* on Poultry 377
- 40.7 Dispersal 378
- 40.8 Bed Bug Control in Poultry Facilities 378
- 40.9 Insecticide Assays 379
- References 380

Part VII Legal Issues 383

41 Bed Bugs and the Law in the USA 385

Jeffrey Lipman and Dini M. Miller

- 41.1 Introduction 385
- 41.2 Registration of Pesticides 386
- 41.3 Legal Requirements Regarding Who Can Apply Pesticides in the USA 386
- 41.4 Legal Requirements for PMPs Regarding the Standard of Care 387
- 41.5 Public Health Acts Regarding Bed Bugs 387
- 41.6 Bed Bug-related Statutes, Laws, and Ordinances 387
- 41.7 Laws Addressing Bed Bug Remediation 389
- 41.8 Tenants and Public Housing 391
- 41.9 Legal Standing Clients Encountering Bed Bugs in Temporary Occupancies 392
- 41.10 Bed Bug Lawsuit Landscape 392
- 41.11 Conclusion 393
- References 394

42 Bed Bugs and the Law in the United Kingdom 397

Clive Boase

- 42.1 Introduction 397
- 42.2 Training of Pest Management Professionals 397
- 42.3 Bed Bug Pesticide Approval 398

- 42.4 Tenants, Guests and Bed Bugs 399
- 42.5 Local Authority Duties and Powers Regarding Bed Bugs 399
- References 400

43 Bed Bugs and the Law in Australia 403

Toni Cains, David G. Lilly and Stephen L. Doggett

- 43.1 Introduction 403
- 43.2 Registration and Use of Bed Bug Management Products 403
- 43.3 Legal Requirements of Pest Management Professionals 404
- 43.4 Public Health Laws Regarding Bed Bugs 404
- 43.5 Tenancy and Public Housing 405
- 43.6 Bed Bug Legal Cases 406
- References 406

44 Bed Bugs and the Law in Asia 409

Andrew Ho-Ohara and Chow-Yang Lee

- 44.1 Introduction 409
- 44.2 Registration and Use of Bed Bug Management Products 409
- 44.3 Legal Requirements for Pest Management Professionals 410
- 44.4 Bed Bug Legal Cases 411
- 44.6 Future 412
- References 412

45 On Being an Expert Witness 413

Paul J. Bello and Dini M. Miller

- 45.1 Introduction 413
- 45.2 What is an Expert Witness? 413
- 45.3 The Expert's Role 414
- 45.4 Providing Expert Testimony 414
- 45.5 Bed Bugs in a Court Case 415
- 45.6 Summary 416
- References 417

Part VIII Bed Bugs: the Future 419

46 Bed Bugs: the Future 421

Chow-Yang Lee, Dini M. Miller and Stephen L. Doggett

- Summary 426
- References 426

Index 429