Institution: **University of Sheffield**

Unit of Assessment: **5 - Biological Sciences**

Title of case study: **Towards Eradicating a Global Insect Pest**

1. Summary of the impact

An academic from the University of Sheffield assisted the USA's Environment Protection Agency (EPA) in producing National (USA) standards, guidelines, and recommendations to drive the efficacy testing of commercial products for controlling bed-bug infestations. Sheffield was approached because of the excellence of Professor Siva-Jothy's research group in establishing key aspects of ecology and behaviour that underpin our knowledge of bed bugs, and therefore, their control. Siva-Jothy agreed to join the EPA Scientific Advisory Panel in 2012 and the regulatory document (SAP# 2012-03) that he was involved in producing is the first to regulate and provide evidence-based guidance for the bed-bug control industry, which is dealing with a population explosion because of inappropriate control practices and chemicals. Bed-bug infestation is a serious and growing health issue in many, and perhaps most, urban population centres worldwide, with litigation costs in the hospitality industry in the USA already exceeding $500M *p.a*. The new regulations have significant impact on health and welfare and public policy.

2. Underpinning research

Bed bugs have recently emerged as a global pest (e.g. Doggett *et al.* 2004; *Environ. Health*. 4:30-38). Professor Mike Siva-Jothy has been conducting research on the bed bug, *Cimex lectularius*, in Sheffield since 1999 and has established an international reputation for bed-bug research. His research group have used bed-bugs to study how insect immune systems operate and evolve, and how sexual conflict affects insect evolution of life-history traits (2000-present). Sheffield researchers have included Dr Klaus Reinhardt (who joined Siva-Jothy's group in 2002, and left in 2010 to form his own research group in Tübingen to study reproduction in bed bugs) and Richard Naylor (who joined in 2000 and graduated as a PhD CASE student in 2012) [**R1-3**].

To progress their research aims, the team first had to understand and quantify previously unknown aspects of the bed bug's biology and ecology. For example, in order to understand the context in which this insect's immune organ evolved, it was necessary to understand the ecological context in which it functioned. So, although the primary aim of the research was to address generic questions in evolution and immunity, the team had to start by identifying the natural behaviour and ecology of this insect. Knowledge of these aspects of bed-bug biology is also critical in designing effective control protocols and testing the efficacy of pesticides – the aims of the EPA Scientific Advisory Panel – and underpins the impact described here. The relevant data are captured in 17 research publications spanning 2003-12. The SAP document described in section 4 cites three of these publications [**R4-6**].

3. References to the research

R1 Stutt, A. & Siva-Jothy, M.T. 2001. Traumatic insemination and sexual conflict in the bed bug *Cimex lectularius*. *Proc. Natl. Acad. Sci. USA,* 98, 5683-5687. doi: 10.1073/pnas.101440698

R2 Reinhardt, K., Naylor, R.A., & Siva-Jothy, M.T. 2009. Situation exploitation: higher male mating success when female resistance is reduced by feeding. *Evolution*, 63, 29-39. doi: 10.1111/j.1558-5646.2008.00502.x

R3 Reinhardt, K., Naylor, R.A., & Siva-Jothy, M.T. 2009 Ejaculate compounds delay reproductive senescence while increasing female reproductive rate in an insect. *Proc. Natl. Acad. Sci. USA*, 51, 21743-21747. doi: 10.1073/pnas.0905347106

Research cited in the EPA SAP regulatory document:

R4 Siva-Jothy, M. 2006. Trauma, disease and collateral damage: conflict in cimicids. *Phil. Trans. Roy. Soc. Lond, B* 361, 269-275. doi: 10.1098/rstb.2005.1789

R5 Reinhardt, K., & Siva-Jothy, M.T. 2007. Biology of the bedbugs (Cimicidae). *Annu. Rev. Entomol*, 52, 351-374. doi: 10.1146/annurev.ento.52.040306.133913

R6 Naylor, R. Boase, C.J., Bajomi, D. 2008. Efficacy of (S)-methoprene against the bed bug *Cimex lectularius*. Pp 115–121 in Robinson, W., Bajomi, D. (eds). *Proc. 6th Intl. Conf. Urban Pests*. OOK-Press, Hungary. Available at http://www.icup.org.uk/reports%5CICUP863.pdf

4. Details of the impact

The research has had an impact on **Health and Welfare** (decisions by a regulatory authority have been informed by the research); impact on **commerce** (a business sector has adopted a new policy to which the research has contributed); impact on **public policy** (the policy has informed new regulations, control measures for infection have been improved); and impact on **services** (professional standards have been influenced by the research).

Impact on policy

Professor Siva-Jothy's research expertise informed and guided the task of the US Environmental Protection Agency's Scientific Advisory Panel (SAP) to consider and review methods for efficacy testing of bed bug pesticides [**S1**].

Siva-Jothy was asked to become a member of the EPA Scientific Advisory Panel and to assist in defining product testing and control protocols for bed bugs. He travelled, at the EPA's expense, to attend a 2-day meeting at the Environment Protection Agency conference centre in Arlington, in March 2012 **[S2]**. Notably, Siva-Jothy was the only member of the panel from outside of the USA. The policy document resulting from this meeting defined, for the first time, how products used to eradicate bed bugs should be tested and what variables are required to show that they are effective. The new regulations mean that it will no longer be possible for practitioners to use unregulated control techniques that have previously exacerbated the problem because they (a) failed to control local infestations (which then expand), (b) often enhanced dispersal (because they use non-lethal compounds in generic ways that stimulate the resistant bed bugs to disperse) and (c) produced a distrust of reputable pest-control practitioners, so that infestations went unreported, enhancing population growth. A letter from the Executive Secretary of the EPA Scientific Advisory Panel acknowledges the value of Siva-Jothy's contribution *"It is because of Dr Siva-Jothy's extensive and renown expertise on bedbug life history, behavior and ecology that he was invited to participate in this meeting [the SAP]. The knowledge he has gained from his research experience contributed greatly to the scientific underpinnings of the Panel's advice and recommendations as contained in SAP Minutes #2012-03."* [**S3**].

Impact on Industry and changing practice.

Many legitimate urban-pest controllers were using compounds and techniques designed for other urban insect pests (such as cockroaches or termites), which had no effect on bed-bugs. More worryingly, because there was no informed guidance on the application protocols, they were being used in a manner that was compounding the problem (i.e. producing dispersal). The SAP document defines the objective testing protocols in respect to chemical efficacy by experimental designs that capture efficacy on wild bed-bug populations 'in the field'. This means that the standard, long-established laboratory-based approaches are now considered inadequate. The research output and expertise from Siva-Jothy was critical in informing the design of the protocols

in this document. The SAP document is the first attempt by any government to provide evidence-based guidelines for control practices and pesticide efficacy for this globally resurgent pest. The consequence of this regulation in the USA is that the bed-bug pest control industry is now largely restricted to professional practitioners who follow the guidelines and use chemicals that have been approved *via* the protocols in the SAP document. Untrained, fly-by-night practitioners using cheap, untested chemicals can no longer operate and customers now get an effective professional service. Two main professional bodies currently ensure that the standards in the SAP document are applied by their members: BedBug Central and The National Pest Management Association of America (NPMA). These member associations who provide a broad-based training for thousands of companies across the US, recognise that the research conducted by Siva-Jothy has been core to the provision that has increased the effectiveness of their practitioners [**S4,S5**]. The impact of Siva-Jothy's contributions is confirmed in letters from the Technical Director of BedBug Central, and the Executive Officer of The National Pest Management Association who state that:

> *"Prof. Siva-Jothy's and his group's research (via publication and the plenary to our members) has influenced the practices of BedBug Central and assisted in advancing its recommended protocol which reaches hundreds of thousands of people every year"*, and *"Having Mike present the results of his evidence-based research on bed bug behaviour, ecology and life-history has been crucial in helping the industry develop innovative control strategies across the United States. Our members are involved in thousands of treatments nationwide; therefore the impact of Mike's research is far-reaching and very important."*

Impact on individuals/health.

Best estimates suggest that *ca* 1M people are affected by bed bugs in New York City alone. Figure 1 shows web-site notification of confirmed infestations across the USA: This registry tends to capture hospitality-related infestations, as reported by an affluent, web-literate demographic. The demographic affected by bed bugs is much wider than that represented in the data and, in the developed world, the nucleus of urban infestations tends to be social housing and/or vulnerable members of society.

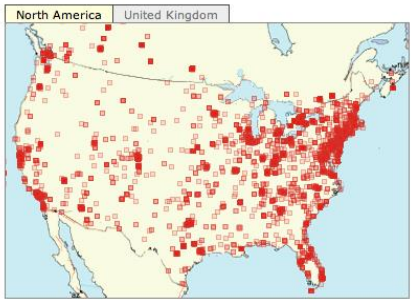

Figure 1. Bedbugregistry data on location of reported bed-bug infestations since 2006. The majority of these are from the hospitality industry: residential infestations are under-represented in these data.

The EPA's web site (http://www.epa.gov/bedbugs/) reflects the urgency for education of the problem. For example, control measures in apartment blocks initiated by a single complaint subsequently revealed that >50% of apartments were infested, with the occupants failing to report despite presenting to doctors with "allergies" – i.e. extensive exposure and reaction to bed-bug bites. The bedbugregistry (http://bedbugregistry.com/metro/) allows self-reporting of infestations (Fig. 1) and is the only organisation tracking infestation at a national scale.

The number of people affected in developed continues to rise, and although bed bugs do not transmit disease, they have a huge economic cost. Extermination and management costs can exceed $6,000 *pa* per apartment; litigation in the hospitality industry exceeds $500M *pa* in the USA, and indirect effects (on mental health, fatigue caused by loss of sleep and itching) are only just beginning to be measured. Although the socio-political relevance of this pest is largest in the USA, it is an increasing if less visible or officially acknowledged problem in London, Paris, Sydney and most major international cities.

Impact timescale

The nature and extent of the impact is long-term: the Environmental Protection Agency document published by the Scientific Advisory Panel (including Siva-Jothy) now underpins product certification, and has galvanised the control industry in the USA to standardise its protocols and codes of practice. There are now standardised, scientifically informed, review, testing and application protocols being implemented. Since the SAP document sets the standard by which other national testing protocols will be developed, the likely impact will reach beyond the USA.

The level of Professor Siva-Jothy's contribution to this impact is underlined by Dr Feldlaufer, an entomologist at the United States Department of Agriculture, Agricultural Research Service (USDA/ARS) who states *"Prof. Siva-Jothy's laboratory has made seminal contributions to our knowledge of bed bugs in the context of modern ecological and evolutionary theory and had generated most of our modern understanding of bed bug biology. The body of knowledge generated by his research effort has provided critical reference sources on which to build control strategies in the United States"* [**S6**].

5. Sources to corroborate the impact

S1 FIFRA SAP document # 2012-03.

This is the EPA regulatory document citing the research described in this Case Study.

S2 http://www.regulations.gov/#!docketDetail;rpp=25;po=0;D=EPA-HQ-OPP-2011-1017

Online resource documenting the EPA meeting, and from where the report can be downloaded.

S3 Letter from Executive Secretary (Laura Bailey), FIFRA SAP, confirming the significant contribution of Siva-Jothy. This letter is quoted above and is available in full on request.

S4 Letter from Technical Director of BedBug Central (www.bedbugcentral.com) (Dr Jeff White), an organisation that informs the pest control industry (it has ≥60 affiliated companies) and provides support for the public (400,000 web-site visitors *pa*), confirming the contribution of the Sheffield group's research to the work of this national advisory body. Quoted from above, and available on request.

S5 Letter from Executive Officer (Jim Fredricks), The National Pest Management Association of the USA, representing >7,000 professional firms across the USA with annual revenue over $3bn, confirming the impact of the data from the Sheffield group on industry activities and guidelines. Quoted from above, and available on request.

S6 Letter from USDA/ARS (Dr M Feldlaufer), Bldg 1040, BARC-East, Beltsville MD20705, USA, confirming the importance of the Sheffield group's research influencing US Department of Agriculture's strategy for controlling bed-bug infestations in the USA. Quoted from above, and available on request.