



# Uncovering the hidden cost of bed bugs

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In the United States, emergency department (ED) visits resulting from bed bugs increased by over 700% between 2007 and 2010 (1), at least 80% of hotels in 2015 had to treat for bed bug infestations (2), and some hospitals lost access to beds nearly every other day due to bed bugs (3). These costs may be just the tip of the iceberg.

For thousands of years, at least as far back as ancient Egypt, bed bugs have afflicted human populations (4), and before the Second World War and the advent of dichlorodiphenyltrichloroethane (DDT) perhaps a third of all major European cities were infested with bed bugs (5). After the invention and widespread adoption of DDT, bed bug prevalence plummeted, but almost immediately resistance to DDT emerged in bed bugs and their numbers began to surge (5, 6). Recent studies in the United States suggest that the incidence of bed bugs may have returned to levels not seen since pre-World War II Europe (7, 8). Despite bed bugs' well-documented negative effects on quality of life and mental health (6, 9, 10), the risk of serious infection and inflammation stemming from their bites (8, 9, 11), the substantial economic costs incurred for treatment/removal (2, 3, 7, 8, 12, 13), and their potential ability to vector Chagas disease (14, 15), antibiotic-resistant bacteria (16, 17), and numerous other human pathogens (9, 18), the scientific community (and funding agencies) have turned a comparatively blind eye to bed bugs (Fig. 1A). A new study by Xie et al. (19) starts to correct this research deficiency by studying the benefits of mandatory bed bug infestation disclosure by property owners. Their study demonstrates—using a mathematical model—that mandatory disclosures of bed bug infestations by landlords can lower economic costs and reduce the overall burden of bed bugs in a relatively short amount of time. The paper by Xie et al. (19) sheds light on the significant epidemiological and economical consequences of bed bug infestation and opens many new avenues for future research.

Bed bugs are endemic on all continents, aside from Antarctica, ranging from the tip of South America and southern Australia through the tropics and up to northern Alaska and Siberia (9). Their dramatic resurgence has left no place untouched: Australia has seen between a 500% (20) and 4,500% (8, 21) yearly increase in incidence, and global searches for “bed bugs” have increased >15-fold since 2004 (Fig. 1B). Although a great deal of uncertainty remains in the exact mechanisms behind their resurgence (7), part of the explanation stems from the incredible resilience of bed bugs. For example, a mark–release–recapture study found that bed bugs can survive in the absence of hosts (e.g., an abandoned apartment) for over 100 days and can readily migrate between neighboring apartments (22), which may facilitate their dispersal via soiled laundry (23). Other explanations include insecticide resistance (5, 6), urbanization (6, 7, 24, 25), and increased population connectivity (e.g., air travel) (5, 6, 23).

The potentially large economic cost of bed bug infestation underlies the main conclusion of Xie et al. (19) that mandatory disclosure is a highly effective strategy, both in terms of economics and of reducing the prevalence of bed bugs. Although a comprehensive economic analysis remains to be done (7, 25), bed bugs are a persistent and costly issue for health care facilities (1, 13), urban environments (6, 7, 24), hotels (2), and office buildings (26).

Regarding health care facility costs, a number of studies highlight the potentially large economic impact of bed bugs. For example, a 937-bed hospital in Cleveland, OH, monitored its inpatient facilities and ED for 1 year for bed bugs. They had 180 infestations, or 1 every 2.2 days (3). Costs were between \$125 and \$1,050 per infestation, with total costs for the year of \$22,844 for the ED and \$55,915 for the hospital. Hospital administrators believed these were all reintroductions, as active monitoring using Verifi Bed Bug traps (FMC)

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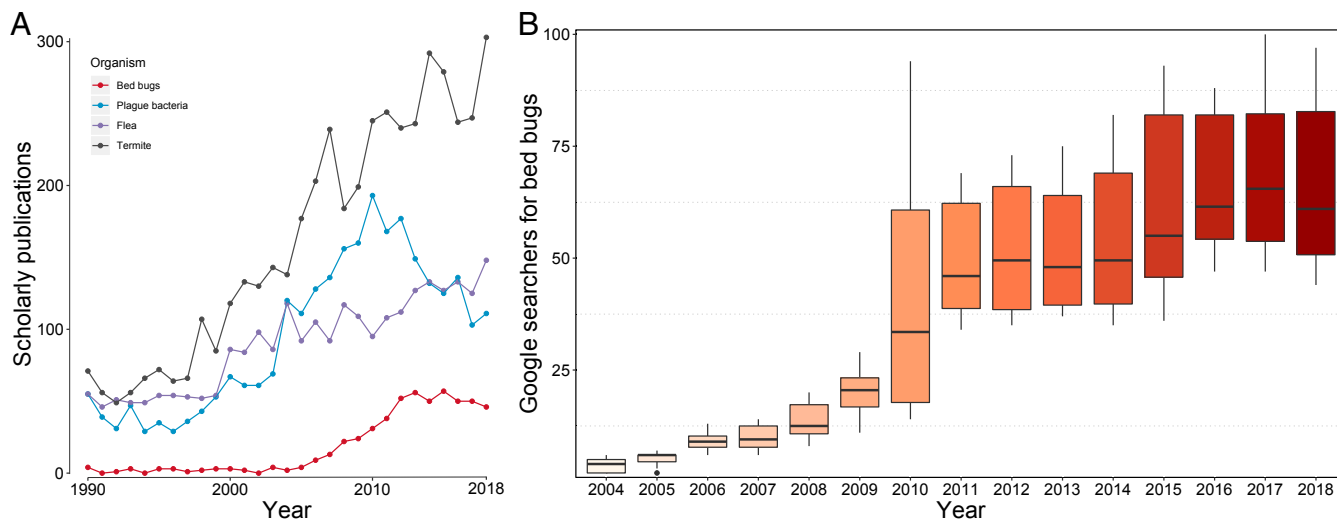
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**Fig. 1. (A)** The number of publications listed on Google Scholar between 1990 and 2018 with “bed bugs” (red), “plague bacteria” (blue), “fleas” (purple), and “termites” (black) listed in their titles. Data were extracted from the Google Scholar application programming interface using custom Python code written by Hufnagel et al. (34). The exact queries were for “bed bug(s)” + “bedbug(s)”, “pestitis”, “flea(s)”, and “termite(s)”. **(B)** The Google search volume aggregated by year between 2004 and 2018. Data are shaded by search volume. For more information see ref. 35.

placed in the ED did not capture any insects, and no bed bugs were found after a bed bug-detecting canine unit was hired to inspect the ED. That infestations are typically due to introduction, as opposed to a persistent reservoir, is supported by genetic evidence from bed bugs sequenced during outbreaks in apartment buildings (27).

For hotels, the situation is equally grim. A survey conducted by Orkin in 2016 (2) found that > 80% of hotels were treated for bed bugs in the past year, with an average cost (treatment and loss of room) of \$6,383 per event. On average, hotels might experience seven bed bug events per year. Additionally, 45% of all surveyed hotels have faced litigation due to bed bugs, with an average cost of \$23,560 per infestation. Beyond these direct costs and legal fees, 98% of hotels reported spending money on active surveillance and prevention programs. However, the costs listed above do not include active monitoring programs or reduced rental occupancy due to concern about bed bug infestation.

The study by Xie et al. (19) is not without important caveats. For example, after relaxing the assumption that populations mixed randomly, they found that the costs and burdens became concentrated such that little overall benefit was realized. Given the evidence for socioeconomic clustering of bed bug infestation (7, 24, 28, 29), structured population mobility and nonrandom bed bug incidence is a critically important line of research to advance. Second, Xie et al. (19) focused on the costs to landlords and did not consider costs and savings to tenants or municipalities. As they note, there could be a considerable increase in net savings if tenants are accounted for. Future work could focus on including costs and savings to all foreseeable actors in the bed bug universe, or incorporating the often unintended effects of human behavior on outbreak dynamics (30), as well as incorporation of more detailed economics (price elasticities,

additional positive or negative externalities (31), and others). Finally, the complexity of human mobility can result in both counterintuitive epidemiological dynamics (32) and/or require high-resolution data (33), both of which must be accounted for in future modeling studies.

Paired with existing research on bed bugs, the Xie et al. (19) study raises a number of important questions for future research. First, what is the risk of infectious-disease transmission from bed bugs? Despite their demonstrated ability to vector many different human pathogens, no causal evidence exists that bed bugs transmit disease regularly between humans (18). Second, what is the true economic cost of bed bug infestations and how are those costs stratified by country, socioeconomic status, race/ethnicity, and so on? Third, what control mechanisms, beyond the disclosure policies advocated by Xie et al. (19), are likely to be most effective (29)? Fourth, because the bed bug has had both its genome (21) and transcriptome (20) sequenced—and molecular tools have been used on a local scale to study spread (27)—how can we best leverage molecular data to understand bed bug population dynamics? Finally, how can we best incorporate human behavior into models of bed bug control?

In September 2011, staff at an office building in Tennessee complained about itching and bites to the state health department (26). A subsequent investigation determined that bed bugs were the cause and the resulting charges cost the company over \$100,000. This company is clearly not alone, but the total burden—both in terms of health and economics—of bed bugs remains almost entirely hidden. The study by Xie et al. (19) is an important advance in economic, epidemiological, and public-policy thinking surrounding one of the most persistent and costly human pests: the bed bug.

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