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Procurement Competence and Framework Agreements for Upgraded Bed Bug Control [*Cimex lectularius* (Hemiptera: Cimicidae)]

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Abstract

The prevalence of bed bugs (*Cimex lectularius* L.) is increasing worldwide. Due to this increase, low-income housing owners and managers need an efficient method for controlling the pests without excessive resource use. The quality of pest control efforts is crucial for efficient eradication. Infestations often need to be approached using a variety of strategies through an integrated pest management (IPM) framework. Efficient eradication is often thought to be the responsibility of the pest control contractor alone. However, the purchase and supply management theory suggests that optimal solutions actually involve sound buyer–supplier relations to support the strategic aim of pest eradication. This study illustrates the positive outcomes of elevating pest management competence on the buyer's part. Further, this study outlines a large-scale purchase situation that quantifies bed bug control efforts, in addition to their outcomes. In total, 11,000 apartment units were observed in Oslo, Norway, over a period of six years. The release and implementation of a procurement officer together with a state-of-the-art pest management framework agreement quickly reversed the consistent escalation of bed bug infestations in the observed units. Observations revealed that the study yielded the most success in eradicating bed bugs by increasing both the number of visits to the infested apartment and the overall duration of control efforts. The improved control was achieved at a reduced cost per infested apartment unit, which allowed for the implementation of bed bug preventive measures and building-wide inspections. The observations made in this study have been discussed in the context of the impact of bed bugs in low-income communities, relative to the factors of pest burden, demography, socioeconomics, and the welfare system in Norway.

Key words: integrated pest management, buyer–supplier relation, purchase strategy, social impact, cost–benefit

The common bed bug (*Cimex lectularius* Linnaeus, 1758) is a nocturnal, blood-feeding insect that behaves as a pest and severe nuisance in human homes. Bed bug infestations in the home are typically prevalent and persistent and are most effectively treated by professional assistance. Bites from bed bugs on humans can induce cutaneous reactions and potential secondary skin infections (Goddard and DeShazo 2009, Reinhardt et al. 2009, Shmidt and Levitt 2012, Phan et al. 2016, Hwang et al. 2018). The negative impact of these pests is somewhat dependent on the infestation level, which can differ greatly from case to case. Heavy infestations cause significant dermatological discomfort, with potential asthmatic complications when insect parts are inhaled, such as fragmented exuvia, histamines, or even bed bug-associated microbes and their metabolites (Arlian 2002, Bonnefoy et al. 2008, DeVries et al. 2018, Kakumanu et al. 2020). Equally important to skin and airway discomfort are the indirect effects of bed bugs on residents' mental health. Bed bugs have been reported to cause stress, sleep disorders, anxiety, and depression in their human hosts (Goddard and DeShazo 2012, Susser et al. 2012, Ashcroft et al. 2015, Wang et al. 2016). Residents with infested homes often suffer from social stigmatization and isolation (Bonnefoy et al. 2008, Bennett et al. 2016, Perron et al. 2018). The presence of bed bugs has been known to have detrimental impacts on businesses, with economic and reputation effects on the housing and accommodation industry, healthcare facilities, offices, and a range of other urban environments (Doggett et al. 2018, Scarpino and Althouse 2019). Over the last two decades, bed bugs have become a major pest concern in developed nations (Reinhardt and Siva-Jothy 2007, Doggett et al. 2018). The worldwide resurgence of bed bugs has been associated with increasing pesticide resistance (Dang et al. 2017, Romero 2018), globalization, and insufficient knowledge of necessary actions to prevent and control their infestations (Doggett et al. 2012, Koganemaru and Miller 2013, Doggett et al. 2018).

The main principles of integrated pest management (IPM) are to combine multiple cost-effective control measures to achieve maximum control effects while minimizing the risks to both people and the environment (Radcliffe et al. 2008, Dhang 2011, Kim et al. 2017). An IPM program is increasingly being considered a necessary measure for bed bug control. The program should be systematically implemented and continuously evaluated for its intended results (Bennett et al. 2016, Romero et al. 2017, Cooper and Wang 2018b, Miller 2018). Pesticides are often used alongside nonchemical interventions such as vacuuming, setting traps, applying heat, freezing, encasing mattresses, and discarding items. Over the last decade, the use of nonchemical methods for bed bug control in response to their widespread resistance to conventional insecticides has increased (Doggett et al. 2018). However, nonchemical methods are often labor-intensive and are consequently costly. Early identification of bed bugs in the home through inspection and regular monitoring is crucial for successful eradication. This is largely because low-level infestations are more easily eliminated than large, widely dispersed infestations (Wang et al. 2009; Vail and Chandler 2017; Cooper and Wang 2018a). A critical element for successful control is that management efforts be aligned with infestation levels so as to prevent excess allocation of resources (Singh et al. 2013, Singh et al. 2017).

Ultimately though, the overarching factor in bed bug elimination is the quality of control measures taken. Efficient bed bug control requires thorough and precise eradication expertise. Pest persistence can be expected if the appropriate and required skills and knowledge are lacking (Doggett et al. 2018). Control in single-unit houses is considered easier to achieve than in multiunit facilities because the complexity increases as the potential for further infestation increases. Additionally, in multiunit buildings, some residents may be reluctant to admit the presence of bed bugs for fear of eviction repercussions and social stigmas (Bennett et al. 2016, Cooper and Wang 2018b, Miller 2018). Single-family homeowners may also be more readily able to implement comprehensive control measures in terms of material, financial, intellectual, and emotional availability, whereas low-income households are commonly forced to settle for cheaper and consequently poorer and less effective control methods, or often none at all (Romero et al. 2017; Cooper and Wang 2018b). To achieve control in complex and socially challenging bed bug infestations, considerable effort should be given to providing essential knowledge for understanding necessary prevention, dispersal, and eradication methods (Stedfast and Miller 2014, Bennett et al. 2016, Gangloff-Kaufmann et al. 2018, Schneider 2019, Alizadeh et al. 2020). Failure to address social elements, coupled with a lack of systematic bed bug management system, may lead to long-term bed bug infestations and continuous pest movement between apartments (Cooper and Wang 2018b, Miller 2018, Wilson 2018). Such contagious infestations cause bed bug reservoirs that make the process of controlling future infestations for the community extremely difficult (Bennett et al. 2016, Schneider 2019).

An understudied aspect of bed bug control is the impact and benefit of acquiring professional pest management services. The subject of purchase and supply management recognizes that a strong theoretical framework is one where procurement places focus on functional strategies for achieving overarching goals (Hesping and Schiele 2015). This particular framework highlights the crucial interplay between the following: 1) promotion of competition through multiple suppliers; 2) assignment of competitive priorities, such as quality, efficiency, innovation, and cost; 3) use of a stepwise procedure to evaluate acquisition and potential trade-off; and 4) collaborative development of a procurement and supplier relationship to optimally support the strategic aim. Continuous improved deliverance of documented pest reductions should be the overall service requirement rather than treatment provision at a low price. With bed bugs specifically, this means pest management efforts should be further delineated into subcategories such as pest inspections, education for residents, control preparation, implementation of control methods, and follow-up evaluations (Bennett et al. 2016; Romero et al. 2017; Doggett et al. 2018). Each of these subcategories would then be evaluated according to quality, efficiency, innovation, cost, and the overall strategic aim. Because the end goal is complete bed bug eradication, a continuous evaluation is required to ensure that the process is beneficial cost-wise. The evaluation would provide better knowledge of the removal process from initial infestation to eradication for both the procurement officer and the pest management contractor. Further, cost–benefit analyses can be conducted to identify trade-offs between eradication measures so as to continually improve control efforts.

Bed bug management is a complex process, often extending beyond single infestation instances (Bennett et al. 2016, Romero et al. 2017, Cooper and Wang 2018b, Miller 2018, Wilson 2018). Because bed bug management is a continuously adapting process, it is unlikely that one supplier is capable of being a supreme provider of all treatment stages, i.e., inspections, desiccant dust application, and heat treatment, among others. Although a single all-in-one treatment for eradication is a tempting solution, a broader approach that promotes supplier competition, and collaboration could promote the quality of individual treatment stages (Hesping and Schiele 2015). This multi-angled approach to procurement is not a common strategy in bed bug control, because of the lower cost in traditional pesticide applications when compared with the more complex IPM approach (Wang et al. 2016, Cooper and Wang 2018b, Schneider 2019). For single-household eradication, using an IPM approach is less of a need, but larger enterprises (multiunit facilities) would benefit from a systematic and coordinated approach. Without confidence in identifying procurement competence for efficient and effective pest eradication, building and individual unit owners often pay expensive rates for largely ineffective tactics that ultimately fail to resolve infestations (Bennett et al. 2016, Romero et al. 2017, Schneider 2019).

The Norwegian welfare system advocates a social equity profile that aims to secure high-quality public services for all residents. This system sees a multitude of basic services supported through public funds to foster equality among households and living conditions. Low-income residents can be assigned municipal housing if their existing living conditions do not meet the standards of the welfare system (Jenssen et al. 2020). With this system in place, local authorities bear the responsibilities of pest control and bed bug management. Typically, large-scale procurement acquisitions are made on a supply and demand basis for managing infestations such as bed bugs.

In this study, the effect on the cost and quality of bed bug management was investigated on the basis of the implementation of a state-of-the-art management framework coupled with the provision of information and improved knowledge on proper control and monitoring procedures. Housing units of a major public housing owner in Norway were observed for the duration of the study. To compile a coherent dataset and effectively contribute to ongoing research to improve IPM going forward, the study results were compared to the overall societal factors in Oslo, as well as known pest occurrences throughout Norway.

Materials and Methods

Pest Control System in Norway

Pest control practices in Norway are controlled through the targeted Pest Control Regulation (HOD 2000) and general Norwegian legislation such as the Norwegian Public Health Act, the Pollution Control Act, the Working Environment Act, and the Animal Welfare Act. The Pest Control Regulation states that an approved pest control technician (PCT) must successfully complete two written examinations following the completion of a theoretical authorization course hosted by the Norwegian Institute of Public Health (NIPH). A newly appointed PCT must also complete a training course ('traineeship') of 40 varied pest control assignments under the supervision of an approved senior PCT. Norwegian pest control companies (PCCs) are regulated by written record keeping describing different pest species and the appropriate control measures taken in each case. In addition to providing a systematic approach for pest eradication measures, these records provide an overview, and reference guide for infestation rates.

Study Area

All tests and observations were conducted in Norway, a Scandinavian country in Northern Europe that is home to 5,380,000 people (SSB 2020). Specifically, the study area was targeted to Oslo, the country's capital city that is also the largest county with 450,000 residents. Oslo is made up of 15 city districts, including the poorest and richest areas in the country (Barstad and Kirkeberg 2003, Jenssen et al. 2020).

The Municipal Undertaking for Social Housing in Oslo, Boligbygg Oslo KF (BBY), is the major government-subsidized landowner in the country, responsible for allocating apartments to social welfare clients in need of residence. Residents housed through BBY range from low-income senior citizens to asylum seekers, to work-incapacitated individuals, to alcoholics, and drug addicts. From 2013 to 2019, BBY was responsible for allocating 10,123–11,363 apartments (total living space of ~1 million m^2) to more than 25,000 residents across all city districts (Fig. 1). Overall, 2% of all BBY apartments included in this study were single-family or duplex houses, while 8% were home in 'row houses.' In addition, 33% of

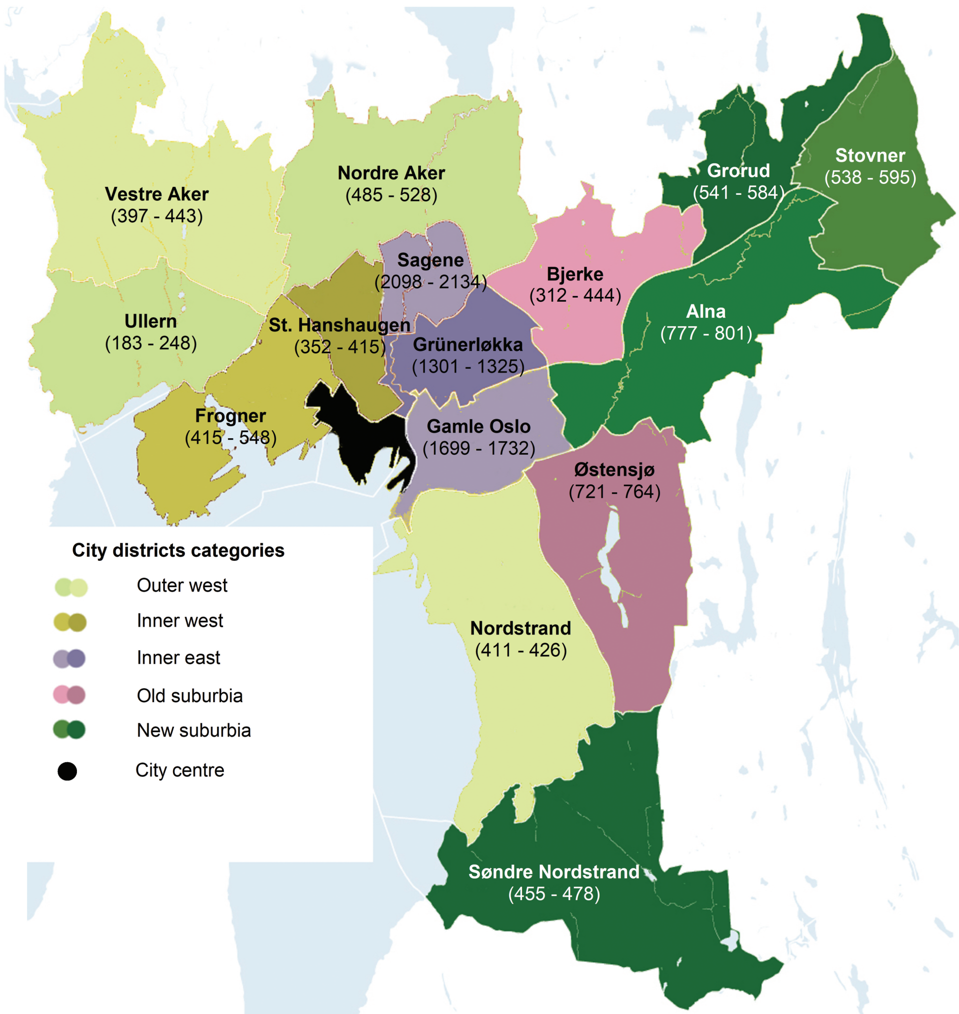


Fig. 1. City districts and city district categories in Oslo. The range of apartments managed by Boligbygg Oslo Kommunalt Foretak in each city district for 2015–2019 is shown in brackets.

apartments were located in blocks of flats with varied ownership, while 57% of apartments were located in blocks of flats fully owned by BBY. For all BBY housing units, tenants are responsible for standard indoor maintenance, while BBY is responsible for technical and external maintenance for everything building related. Tenants are contractually obligated to contact BBY upon the suspicion of pests, after which BBY evaluates the situation, alerts a PCC if necessary, and is responsible for covering all pest management costs.

BBY Procurement Development

Pest control in BBY has undergone a number of shifting management regimes over the years. Prior to 2013, the number of registered pest control job opportunities in BBY's residential properties was modest, limited to isolated cases of rodents, cockroaches, and bed bugs. At that time, pest management practices consisted of case-by-case controls coupled with only a handful of single-building contracts. The PCC was paid a flat rate per building to solve all pest problems without participation or coordination from the building manager. The earliest pest management regime included no specific mention of bed bug problems and consequently only had partial guidelines and specifications for appropriate eradication methods.

During 2013–2014, bed bug infestation levels began to rise, which prompted BBY to develop a strategy outline for the emerging pest. An individual with no formal pest control training was assigned as the coordinator for all PCCs. This new strategy focused on service contracts for rodent control, while pest cases involving insects were dealt with on a case-by-case basis. The strategy also only contained a loosely defined advisory for conducting pest remediation services. Criteria for coordinators to assess when selecting pest contractors was weighted at 80% attributed just to cost, with the remaining 20% leftover for competence and efficiency of service delivery. Contracts between BBY and PCC stated that the selected PCC should service selected BBY properties and that the work should be done in such a way that the results would render BBY's governing role unnecessary.

In 2015, in response to escalating infestation rates, BBY realized that it needed assistance to make much-needed improvements to bed bug management practices. Through a joint venture with the public administration of Oslo, NIPH, and PCC contractors, BBY was able to develop an intermediate pest management strategy. The strategy changed the focus towards procurement competence, measures to prevent infestation, control method application, and responsibility for pest maintenance. The need for a dedicated, skilled person to administer, coordinate, and monitor bed bug remediation efforts was defined as a prerequisite to ensure the value of the investment made by BBY. At the end of 2015, BBY employed a procurement officer, Espen Roligheten, equipped with a Master's degree in bed bug biology and 10 years' experience as a PCT.

The intermediate pest management strategy paved the way for a framework agreement entered into from 2017 to 2019. This framework was used as a foundation for the existing bed bug elimination strategy that outlines the process for selecting pest control contractors. Through a tendering process, BBY and selected contractors entered into a four-year framework agreement. Framework agreements are particularly beneficial when the buyer needs to develop a strategic relationship with the supply chain over a long period of time. Based on these agreements, as well as previous contracts between buyers and suppliers, the weighting for cost was reduced to 40% of the total assessment, with 35% dedicated to solution quality, 20% to PCT competence, and the remaining 5% to the environmental health and safety profile of the PCC. The framework stipulated that the intensity of infestations be assessed and classified as heavy, intermediate, or light, with control solutions deployed accordingly. Infestation levels were determined through a visual inspection by the procurement officer or PCT following the procurement officer's guidelines. Neighboring rooms or apartment units were also inspected. Infestation levels were determined by the number of bed bugs observed and the assumed time since introduction (e.g., observed fecal spots and other bed bug remains). These factors were considered in combination with a subjective observation of apartment conditions (i.e., clutter, cracks, and crevices). The number of remediation visits to the infested unit by the PCT was dependent on the infestation level: 1) four or more for heavy infestations; 2) up to three for intermediate infestations; and 3) one for light infestations. The framework also stipulated that—once bed bugs had been detected in a unit—control measures had to be initiated within two weeks, with evaluation no longer than 8–10 weeks after the eradication by either visual inspection or interceptor traps. The preferred evaluation method is interceptor traps that are left in the unit for 14 d. Inspections are conducted occasionally for evaluations in cases where PCTs assume tenant cooperation to be low. The use of interceptor traps is also often supplemented with visual inspections.

Since 2016, building-wide inspections for bed bugs have been performed by a dedicated procurement officer and selected PCCs. Access to apartments is assured through notification letters previously issued to tenants, followed by a team of inspectors conducting a systematic visual inspection focused around beds, sofas, and other potential resting areas. These visual inspections take between 5 and 10 min for each apartment, with special attention given to units neighboring infested apartments. The focus of these building-wide inspections was directed toward buildings and areas suspected of having a high infestation risk based on both the number of previous incidents and the frequency of new infestation reports in BBY's electronic apartment database.

Control Methods in Use

Prior to 2013, targeted bed bug control methods were not yet specified in official BBY documents. Consequently, no systematic inspections were conducted. Infested housing units were only identified after residents filed infestation reports. From 2013 to 2015, remediation methods mostly consisted of a spray pesticide formulation. A few furniture freezing and whole-apartment heat treatments were documented during this time. In 2016, two companies had become the primary contractors for bed bug eradication—Anticimex AS and Rentokil Initial plc—with one focusing treatment on using desiccant dust, while the other applying the whole-apartment heat treatment. Both companies would often use freezing as a supplementary method for treating furniture from infested units. The furniture was placed in large, refrigerated containers at −35°C for more than 48 h. Steaming and/or vacuuming was occasionally used when the infestation was deemed light enough. These methods were often used in addition to dusting or heating. Conventional pesticides were rarely used but would occasionally be applied as a minor supplementary treatment component when dealing with severe infestations.

Data Acquisition

Information on the national infestation levels of the most significant indoor insect pests was collected from the NIPH database, which houses information needed for monitoring many of the urban insects in need of control. To align national statistics with BBY's data, indoor pests were grouped into the following categories: 1) bed bugs (*C. lectularius*), 2) black garden ants (*Lasius niger*), 3) long-tailed silverfish (*Ctenolepisma longicaudatum*), 4) wasps (*Vespula* spp.),

5) structure-infesting ants (*Camponotus* spp. and *Monomorium pharaonis*), 6) cockroaches (*Blattella germanica*), 7) beetles (*Attagenus smirnovi*, *Hylotrupes bajulus*, and *Anobium punctatum*), and 8) moths (*Tineola bisselliella* and *Tinea pellionella*).

This study involved reviewing data from BBY's electronic apartment database to effectively evaluate the performance of BBY's upgraded bed bug control efforts. This review included PCC eradication instances in the BBY electronic billing system and the PCT-delivered written records to efficiently describe the control efforts conducted. The variables recorded for this study were as follows: 1) *number of apartments infested*, which is the overall percentage of apartment units infested in BBY per year; 2) *pest management response time,* which is days from first infestation report to first PCC visit; 3) *duration of remediation in the apartment*, which is days from the first visit to the final inspection in the infested apartment unit (+1 day to avoid zeros, if the infestation was detected and control immediately initiated during an ongoing control program); 4) *number of visits to the apartment*, which is the total visits to the infested apartment unit, including final inspection; 5) *success rate*, which is the percentage of treated apartment units without infestation relapse; 6) *total cost*, which is the overall annual control cost to BBY; 7) *cost per apartment,* which is the cost of all visits to the infested apartment unit; 8) *cost per visit*, which is the cost of individual visits to the infested apartment unit; and 9) *preventive expenses*, which is the overall costs of preventive measures conducted by BBY each year.

To investigate the infestation rate in different parts of Oslo, the 15 city districts were categorized into two groups: one with a higher, above average living condition index (above 6.6), and one with a lower-than-average socioeconomic status (below 6.6). The city districts were further divided into five geographical groups: outer west, inner west, old suburbia, new suburbia, and inner east (Barstad and Kirkeberg 2003, SSB 2020).

Statistical Analyses

Data were analyzed using SigmaPlot for Windows version 14.0, Build 14.0.0.124 (Systat Software, Inc., La Jolla, CA), and Stata for Windows version 15.0 (StataCorp LLC, TX). Analyses of variance (Kruskal–Wallis ANOVA with Dunn's method to separate groups) were used to investigate the differences between years in the number of visits per infested apartment unit, duration of the remediation, cost per infested apartment unit, and cost per visit to infested apartment units. The same method was used to examine variation in bed bug infestation levels among the five geographic city districts. A Mann–Whitney rank sum test was used to investigate the differences in bed bug infestation levels between city districts of higher or lower socioeconomic status. Linear regression correlated the total annual bed bug treatment cost and infestation rate for different years. Logistic regression was used to analyze the difference in eradication success for particular units between years, and mixed-effect logistic regression was used to investigate the difference between years in prevalence of bed bug-infested apartment units. The last analysis included city district as a random-effect variable to adjust for the potential differences between the districts.

Results

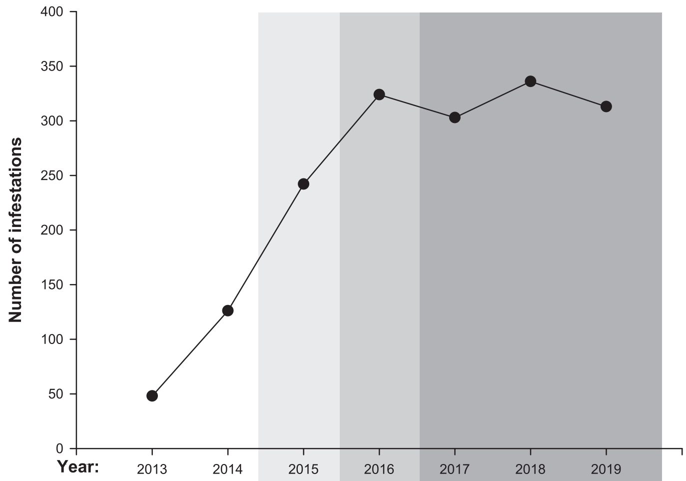
The data on known bed bug cases in BBY's apartments indicated a total infestation rate of ~3% over 2016–2019 (Fig. 2). This accounted for 10% of Norwegian infestations, although the housing stock comprised less than 0.5% of the national total. The most notable discrepancy between BBY and the national pest situation was the proportion of bed bug treatments relative to the treatments for all other pests (Table 1). Overall, 79% of BBY's pest control efforts were directed toward bed bug control compared with 21% nationally. The importance of bed bugs as a major pest for BBY was further emphasized by bed bug treatments having a sevenfold higher control cost per infested apartment unit than that of the second-costliest pest (long-tailed silverfish) and nearly twice the cost of all other pests combined.

The BBY employment of a new procurement officer with training in pest management, combined with a systematic approach of creating a formalized framework agreement, eliminated the significant annual increases in infestations from 2013 to 2016 (Fig. 2; Table 2). A coherent management system also improved bed bug remediation in infested apartment units by significantly increasing the number of pest management visits from 2015 to 2019 (ANOVA: H = 628.26, df = 6, $P < 0.001$; Fig. 2) and the duration of each bed bug remediation between 2016 and 2018 (ANOVA: H = 124.58, df = 4, $P < 0.001$; Fig. 2). Finally, the eradication success rate of bed bugs in the infested apartment units increased from 62.8% in 2015 to a range of 69.0%–74.7% in subsequent years, with significant improvements in 2016 and 2018 (logistic regression: $\chi^2 = 10.061$, $P = 0.039$; Fig. 2). The time taken from initially reporting a bed bug sighting to starting treatment did not change, fluctuating between 22.1 ± 1.7 d and 35.7 ± 2.0 d.

The total annual cost of bed bug treatments in BBY correlates with annual apartment infestation rates (linear regression: $R^2 = 0.988$, $P < 0.001$; Fig. 2). The average cost of treating each bed bug-infested apartment unit increased until it peaked in 2015, after which the cost began to decline. The treatment costs for an infested apartment unit in 2015 and 2016 were significantly higher than in all other years (ANOVA: H = 300.58, df = 6, $P < 0.001$; Fig. 2). The cost of individual visits to infested homes was significantly reduced in 2017, 2018, and 2019 when compared with those of previous years (ANOVA: H = 509.22, df = 6, $P < 0.001$; Fig. 2). This reduction and stabilization of bed bug remediation costs after 2015 allowed for preventive measures to be included within the annual bed bug budget (Fig. 2). Preventive methods included renovating the whole-apartment, new flooring, sealing cracks and crevices, using CO_2 to activate any existing bed bugs hiding in empty apartments, disposing discarded furniture, and inspecting the whole building. In these large-scale, high-risk systems, building-wide inspections were crucial for determining total infestation levels. Only 22.4% of the preventive costs (or 1.7% of the total bed bug costs) were associated with these assessment inspections. However, since 2016, these inspections revealed 32%–36% of all known infestations in BBY. During building-wide inspections, more than 70% of the apartments were entered, with 31%–69% of all infestations detected having not been reported by the inhabitants (Table 3).

Overall, the highest rate of infestation was observed in the inner east city district. The percentage of bed bug infestations was found to be significantly greater than those in the outer west, old suburbia, and new suburbia districts (ANOVA: H = 35.51, df = 4, $P < 0.001$; Fig. 3). It was also determined that the inner west experienced intermediate levels of infestation. Districts with lower socioeconomic status (inner east and new suburbia) experienced significantly higher bed bug infestation levels (2.7% ± 0.5%) than other districts (1.6% ± 0.3%) (Mann–Whitney rank sum test: T = 1678.0, $P < 0.001$; Table 4). Two-thirds of the BBY apartments were located in city districts associated with lower socioeconomic status (Fig. 1), and almost half of those apartments were in the inner east city districts. Across all years evaluated in this study, apartments in buildings fully owned by BBY made up 63% of the BBY apartment stock with 83.0% ± 1.9% of total incidents of bed bug infestations.

	Pest management regime	Apartments infested (%)	Response time (d)	Number of visits	Duration of remediation (d)	Success rate (%) / Odds ratio (95%-CI)	Total cost	Preventive expenses
2013	Initial strategy	0.47	N.A.	1.00 a	N.A.	N.A.	1 013	0
2014	Initial strategy	1.24	N.A.	1.00 a	N.A.	N.A.	2 673	0
2015	Intermediate strat.	2.25	30.0 ± 4.7	1.99 ± 0.15 b	24.7 ± 3.3 a	62.8 / 1	5 778	0
2016	Interm. strat. with p.o.	2.95	27.4 ± 2.0	2.44 ± 0.10 b	44.0 ± 2.0 b	71.7 / 1.50 (1.05-2.15)	7 602	292
2017	Fr. agre. with p.o.	2.72	22.1 ± 1.7	3.07 ± 0.11 c	55.7 ± 2.2 c,e	69.0 / 1.32 (0.92-1.88)	6 522	1234
2018	Fr. agre. with p.o.	3.01	35.7 ± 2.0	3.48 ± 0.11 d	69.4 ± 2.9 d,e	74.7 /1.75 (1.22-2.50)	7 116	169
2019	Fr. agre. with p.o.	2.75	31.9 ± 2.2	4.12 ± 0.13 e	59.3 ± 2.4 e	69.3 /1.34 (0.94-1.91)	6 815	458



	2013	2014	2015	2016	2017	2018	2019
Cost per apartment:	21.1 ± 0.5 a	21.2 ± 0.3 a	24.0 ± 0.4 b	23.6 ± 0.3 b	21.5 ± 0.3 a	21.2 ± 0.3 a	21.7 ± 0.3 a
Cost per visit:	21.1 ± 0.5 a	21.2 ± 0.3 a	20.6 ± 0.9 a	18.9 ± 0.4 a	14.1 ± 0.4 b	11.5 ± 0.4 c	9.3 ± 0.3 d

Fig. 2. Bed bug infestation levels, control effects, and control costs (in 1,000 NOK) of bed bug management in Boligbygg Oslo Kommunalt Foretak apartments in different pest management regimes for 2013–2019. The following information is presented in the table insert: *Pest management regime* (p.o. = procurement officer; fr. agre. = framework agreement), *Apartments infested*, *Response time*, *Number of visits*, *Duration of remediation*, *Success rate*, *Total cost*, and *Preventive expenses* (in 1,000 NOK), and below the figure: *Cost per apartment* and *Cost per visit*. Owing to a lack of information in Boligbygg Oslo Kommunalt Foretak databases, some variables do not have data from 2013 and 2014 (marked N.A.) or data from a subset of bed bug assignments in 2015. Different letters in a variable indicate significant differences between years (Dunn's method, $P < 0.05$), except in *Success rate* (percentage of treated apartments without a relapse of infestation), where the odds ratios indicate significant differences between 2015 and following years.

Discussion

This study shows that the incorporation of procurement competence—i.e., pest management knowledge with regard to quality remediation efforts into the housing management system—improves bed bug control. A newly recruited procurement officer was able to succeed in increasing the efficiency of bed bug control while reducing the potential for reinfestation. This was achieved by increasing the number of visits and the duration of pest control efforts in infested apartment units. These results are unsurprising due to the fact that BBY developed away from its relatively 'hands-off' approach to bed bug management by hiring an expert with recent experience as a PCT and engaging in state-of-the-art pest management efforts. Comparable effects have been observed in low-income urban neighborhoods in the USA when competent pest management methods have been applied (Bennett et al. 2016, Cooper and Wang 2018b, Wang et al. 2018). The improved bed bug remediation also fits the procurement theory that focuses on functional strategies to ensure that the acquisition (framework agreement and the subsequent pest control contracts) is both cost-beneficial and creates a sound buyer–supplier relationship (Hesping and Schiele 2015). The most interesting finding of this study is that improvement to bed bug elimination methods came at a reduced cost. The drop in the average cost per infested apartment unit was correlated to the pest management framework agreement, which places greater responsibility for successful eradication on the pest management contractor (supplier side) and aims for strong collaboration between PCCs and the procurement officer.

During the study period, the main financial benefit for BBY was the reduction in escalating expenses that arose from new and recurring bed bug infestations. In addition, the reduction in the average cost per infestation supported the value of employing a knowledgeable procurement officer. The ability to obtain a structural overview from a procurement office—who has the experience of identifying problem areas or buildings—is of paramount importance (Cooper and Wang 2018b, Miller 2018, Schneider 2019). Being able to work systematically across entire properties performing building-wide inspections and applying efficient control methods has also greatly reduced the numbers of non-reported infestations. An increased search for unknown infestations in problem buildings may have partly contributed to masking a reduction in infestation rates, but it is believed to be beneficial for the long-term. The city-wide economic and societal benefits of implementing a procurement system at this scale are difficult to quantify. However, they are expected to be significant because it appears that the escalation of the bed bug problem has been reversed. This reversal should go a long way to prevent bed bug concerns from spilling over to other buildings, districts, or parts of society. Although the engagement of a procurement officer is already considered a success, the number of infestations still needs to

Table 1. Average proportion of housing units infested with urban insect pests in Norway and in Boligbygg Oslo KF between 2016 and 2019

Pest	National (%)	BBY (%)	Cost for BBY (1000 NOK)
Bed bugs	21.2 ± 1.6	79.2 ± 0.8	21.2 ± 0.3
Black garden ants	27.5 ± 3.7	4.5 ± 0.8	1.6 ± 0.1
Long-tailed silverfish	20.0 ± 8.0	1.6 ± 0.9	3.0 ± 0.3
Wasps	10.7 ± 1.3	1.3 ± 0.5	1.6 ± 0.1
Structure-infesting ants	10.4 ± 0.9	0.3 ± 0.1	2.2 ± 1.3
Cockroaches	5.2 ± 0.7	9.1 ± 0.9	2.6 ± 0.1
Beetles	4.2 ± 0.4	3.9 ± 1.5	N.A.
Moths	0.9 ± 0.1	0.2 ± 0.1	N.A.

Also listed are the remediation costs (in 1,000 NOK) per infested apartment unit in BBY's housing stock in 2019. Missing data are noted as N.A.

Table 2. Prevalence of bed bug infestations in Boligbygg Oslo KF apartments under the different pest management regimes from 2013 to 2019

Variable	*P*-value	Pest management regime	Category	Infestation prevalence (apartments)	Odds ratio (95%CI)
Year	<0.001	Initial strategy[a]	2013	0.47% (10,123)	0.16 (0.12–0.23)
		Initial strategy[a]	2014	1.24% (10,142)	0.45 (0.36–0.55)
		Intermediate strategy[b]	2015	2.25% (10,744)	0.82 (0.69–0.97)
		Intermediate strategy w/ proc. officer[b]	2016	2.95% (11,001)	1.10 (0.93–1.29)
		Framework agreement w/ proc. officer[c]	2017	2.72% (11,127)	1.01 (0.86–1.19)
		Framework agreement w/ proc. officer[c]	2018	3.01% (11,181)	1.13 (0.96–1.32)
		Framework agreement w/ proc. officer[c]	2019	2.75% (11,363)	1

Presence and absence data of bed bugs in apartments were analyzed using mixed-effect logistic regression with city district as a random-effect variable. The random-effect variable, used to adjust for potential differences between districts, improved the model (estimate: 2.334, $P < 0.001$) and determined that city district is an important factor explaining bed bug prevalence.

Pest management regimes:

[a]Initial strategy: one person without any formal pest control training was assigned as the coordinator of pest management agreements with PCCs.

[b]Intermediate strategy: bed bug prevention, detection, application of effective control methods, and pest reduction responsibility were identified as important elements of efficient remediation.

[c]Framework agreement w/ proc. officer: employment of a procurement officer to administer bed bug remediation under a framework agreement lasting four years. The selection criteria for contractors were price (40%), the quality of the suggested solutions (35%), the competence of the designated PCTs (20%), and the environmental health and safety profile of the PCC (5%).

Table 3. The outcomes of Boligbygg Oslo KF building-wide inspections performed by the procurement officer and pest control contractors under the different pest management regimes for 2013–2019

	Pest management regime	Buildings inspected	Apartments inspected	Apartments accessed (%)	Infested apartments (%)	Unreported infestations (%)
2013	Initial strategy[a]	0	–	–	–	–
2014	Initial strategy[a]	0	–	–	–	–
2015	Intermediate strategy[b]	1	45	97.8	**15.9**	100
2016	Intermediate strategy w/ proc. officer[b]	14	955	85.5	**12.7**	69.2
2017	Framework agreement w/ proc. officer[c]	32	1760	82.1	**7.7**	69.4
2018	Framework agreement w/ proc. officer[c]	32	1314	70.2	**13.3**	30.9
2019	Framework agreement w/ proc. officer[c]	24	1224	90.4	**9.9**	46.2

[a]Initial strategy: one person without any formal pest control training was assigned as the coordinator of pest management agreements with PCCs.

[b]Intermediate strategy: bed bug prevention, detection, application of effective control methods, and pest reduction responsibility were identified as important elements of efficient remediation.

[c]Framework agreement w/proc. officer: employment of a procurement officer to administer bed bug remediation under a framework agreement lasting four years. The selection criteria for contractors were price (40%), the quality of the suggested solutions (35%), the competence of the designated PCTs (20%), and the environmental health and safety profile of the PCC (5%).

continuously decrease to minimize the strain on tenants, and reduce the overall economic burden on BBY. As of 2019, approximately a quarter of the apartments experienced some level of reinfestation. Whether these reinfestations are the result of failed treatments or the introduction of new bed bugs by the tenants is unknown. The relatively high number of infestations detected during building-wide inspections does however point to a high incidence of unidentified infestation sources in the building stock. If future inspection efforts focused on known problem buildings or areas, and inspections were combined with tracking of infestation sources, BBY might become even more successful in reducing the overall risk of bed bug reestablishment and dispersal.

Another factor that may contribute to bed bug dispersal is the response time between the initial infestation report and treatment initiation. Delayed treatments allow for bed bug populations to increase in size. This increase presents a risk of bed bugs traveling to adjacent apartment units and/or being transported to new locations within the infested unit itself. Treatment response time should be minimalized to amend this potential issue and reduce the inconvenience of the infestation for the tenants.

As noted above, there is always a potential for bed bug dispersal between different official stakeholders in Oslo. Bed bugs are known to be a recurring pest issue in many service facilities, including facilities that provide temporary housing, substance abuse care, mental health care, and other social services used by residents living in BBY's apartments. Bed bugs are known to 'hitchhike' by attaching themselves to human belongings and traveling with them between locations and buildings. Once inside a building, bed bugs can easily disperse themselves (Wang et al. 2010, Booth et al. 2012, Saenz et al. 2012, Fountain et al. 2014, Cooper et al. 2015). Social service and healthcare facilities are also frequented by non-BBY citizens who may inadvertently pick up a bed bug and contribute to further dispersal across the city. It is recommended that all such facilities that may potentially serve as bed bug sources be identified to limit potential dispersal and infestation numbers throughout the city (Schneider 2019). Disclosure policies and institutional collaboration can potentially address this problem (Xie et al. 2019). Service organizations such as BBY should join forces with other institutions to address bed bug infestation management on a broader scale within the city of Oslo (Schneider 2019).

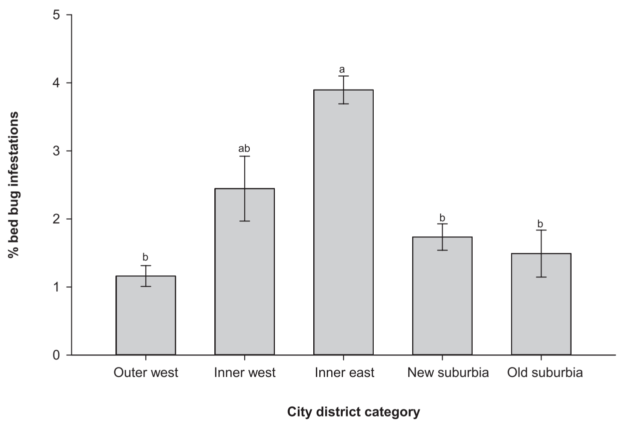


Fig. 3. Bed bug infestations in Boligbygg Oslo Kommunalt Foretak apartments in the different city district categories for 2015–2019 (average percentage ± SE). Different letters indicate significant differences in infestations between categories (Dunn's method, $P < 0.05$).

Most inhabitants of Norway live in decent economic situations. These households are normally capable of addressing emerging pest situations, with homeowner insurance often covering privately encountered pest management issues. However, BBY has a unique management challenge as its clients tend toward lower socioeconomic classes. BBY's pest management portfolio clearly reflects its role as a provider of social housing, operating in an urban environment where bed bugs are one of the main pest species (Bonnefoy et al. 2008, Mallis et al. 2011, Romero et al. 2017, Cooper and Wang 2018b, Wang et al. 2019).

The descriptive statistics presented in this study align with infestations in other countries where bed bugs have a major impact on people of lower socioeconomic classes, specifically in densely populated areas (Wang et al. 2016, Cooper and Wang 2018b, Miller 2018, Wilson 2018, Trajer et al. 2019). At the national level, Oslo and its immediate surroundings stand out because approximately one-fifth of all Norwegians live within this small area. In addition, the city-specific socioeconomic data for Oslo is influenced by BBY's housing stock, which aggregates residents with lower incomes into the most densely populated locations. These locations are commonly the most severely affected by bed bug infestations. Using living condition indexes to characterize districts most at risk to bed bug infestations presents a few challenges when weighting different

Table 4. Recorded bed bug infestations in Boligbygg Oslo KF apartments in different city districts for 2015–2019

			Percentage of infestations					
City district	City district category	Living condition index	2015	2016	2017	2018	2019	Average
Vestre Aker	Outer west	2.0	0.8	0.7	1.0	2.1	0.9	1.1 ± 0.3
Ullern	Outer west	2.3	1.1	0.0	0.4	1.2	2.4	1.0 ± 0.4
Nordstrand	Outer west	2.8	1.7	2.1	2.1	1.9	0.9	1.7 ± 0.2
Nordre Aker	Outer west	2.8	0.6	1.1	0.6	1.1	0.4	0.8 ± 0.1
Frogner	Inner west	4.2	0.7	1.2	0.9	1.1	2.6	1.3 ± 0.3
St. Hanshaugen	Inner west	5.7	2.6	5.3	4.1	3.4	2.7	3.6 ± 0.5
Østensjø	Old suburbia	5.0	0.8	1.1	3.2	2.8	3.0	2.2 ± 0.5
Bjerke	Old suburbia	6.5	0.0	0.6	0.9	1.5	1.1	0.8 ± 0.3
Higher socioeconomic status:			1.0 ± 0.3	1.5 ± 0.6	1.7 ± 0.5	1.9 ± 0.3	1.8 ± 0.4	**1.6 ± 0.3**
Grünerløkka	Inner east	6.7	3.5	3.4	3.5	3.6	3.5	3.5 ± 0.0
Sagene	Inner east	6.7	2.4	4.9	4.4	4.7	3.7	4.0 ± 0.5
Gamle Oslo	Inner east	8.0	5.2	5.1	3.6	3.7	3.2	4.2 ± 0.4
Alna	New suburbia	7.2	0.8	1.3	1.8	3.1	2.1	1.8 ± 0.4
Søndre Nordstrand	New suburbia	7.2	0.7	1.5	0.7	1.1	1.3	1.1 ± 0.2
Stovner	New suburbia	7.8	1.1	1.2	2.1	2.8	3.7	2.2 ± 0.5
Grorud	New suburbia	8.3	1.1	2.0	1.5	1.9	3.1	1.9 ± 0.3
Lower socioeconomic status:			2.1 ± 0.6	2.8 ± 0.6	2.5 ± 0.5	3.0 ± 0.5	2.9 ± 0.3	**2.7 ± 0.5**

City districts were divided into two groups according to their living condition index score, where ten represents the poorest conditions (Statistics Norway 2008). The index includes the following components: access to social help, mortality, disability insurance, rehabilitation money, unemployment, and transitional benefits.

Average = average infestation per city district across all years.

Higher/lower socioeconomic status = average infestation in the two groups per year and across all years.

parameters (SSB 2020), particularly regarding study-specific coarse groupings. It is interesting to note that city districts identified as having the highest number of socioeconomic challenges 20 years ago (Barstad and Kirkeberg 2003) are still considered to have the highest number of challenges today (Jenssen et al. 2020). This demonstrates how low-income tenants in BBY apartments benefit from the welfare system, as their landlord covers all bed bug remediation costs. Low income citizens who are not entitled to the same financial support may encounter infestations although they have better living situations. In some cases, they may even be more adversely affected because of the high cost of bed bug control. Bed bugs can move easily between societal groups, apartment buildings, and institutions (Cooper and Wang 2018b, Miller 2018; Wilson 2018), meaning it can place a significant economic burden on any Oslo citizen.

BBY's budget is a crucial incentive mechanism for PCCs to deliver high-quality bed bug eradication services. The companies currently employed under BBY's framework agreement are two of the largest PCCs offering bed bug remediation in Norway. Together, these companies perform approximately half of all bed bug removal services in Norway annually (NIPH 2020). BBY's procurement officer and novel management system are considered strong assets by PCC managers, in turn contributing to learning and developing improved pest management. The two PCCs contracted to BBY have reported that they have conducted upgrades to their general control practices based on the BBY framework agreement (Arne Nese, Rentokil Initial, and Erik Thomas Gjølme, Anticimex, personal communication). These upgrades may have additionally influenced the attitude of PCC managers toward optimized bed bug delivery. Because almost half of all infestations in Norway occur within Oslo, attitude shifts may, in turn, positively influence national infestation statistics. Through 2017–2019, the total number of infestations in Norway indeed plateaued (NIPH 2020). However, it is also possible that intensified social support and focus on high-risk areas with systematic building-wide inspections in Oslo may have benefited the national statistics. BBY has, in fact, acted as an extension and education service for several stakeholders managing bed bug infestations in all city districts in Oslo, as well as other cities in the country. Through BBY's transparency, disclosure of efforts, and experience, it has now initiated what may become a fully integrated pest control system for the urban districts of Norway. BBY has used purchase and supply management theory to optimize its bed bug management system (Hesping and Schiele 2015). This optimal handling has been achieved by shifting focus from cost to quality service delivery. BBY evaluates different components of service providers through consistent communication and collaboration with contracted PCCs. In this way, pest management competence is continually improved on both sides.

The natural competitiveness between the two contracted PCCs has probably additionally contributed to improving pest management service quality. Both companies have shifted their eradication methods so significantly that they are almost entirely free of conventional pesticide use. PCCs typically employ long-established control methods; however, there should be room for exploring more novel approaches that can bring innovation into the procurement system. To cater for future pest control challenges, BBY has reserved a considerable budget to escalate current efforts, if and when necessary. If the earmarked funds are not required in response to a long-term reduction in infestation rates, a substantial portion may be dedicated to further improvement methods, including implementing preventive measures, providing resident education, optimizing control strategies, improving the pest management framework agreement, funding control strategy development, or facilitating pest management research. Additionally, stakeholders elsewhere in Oslo—and other cities—may facilitate the initiation of similar undertakings using BBY's newly acquired knowledge of pest management.

The systematic process of establishing a full-scale and coherent system for effective bed bug management has just begun. It is fully expected that various adjustments and improvements will be needed to be made to the process in the future. The nearly instant control effect and monetary impacts from employing a skilled procurement officer indicate the need for improvement. This study highlights the improved use of public finances to better fund effective pest remediation efforts. However, it remains to be seen if this new approach will be enough to reduce current and future bed bug infestation rates in Oslo to the desired levels of below 3%. Further studies are needed to determine the amount of time needed to achieve the desired results in Oslo and other cities in Norway.

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Data Availability

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

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