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Distribution, abundance, and seasonal patterns of *Plodia interpunctella* (Hübner) in a commercial food storage facility

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Populations of *Plodia interpunctella* (Hübner), the Indianmeal moth, were monitored inside a 105,000 m^3 food warehouse in the central United States for a 3-year period, using pheromone-baited traps for males. A total of 52 traps were placed in the warehouse, which was roughly divided into four main areas. Ten traps were placed in the grounds outside the warehouse. Total inside moth catch was nearly 50,000 for the three-year study, suggesting a large population was present within the warehouse. Moth captures both inside and outside the warehouse generally peaked during the summer months, and few adult males were caught during the cooler months of the year. Within a year, trap locations where greater numbers of moths were captured varied over time within the warehouse. Trap locations in an area where food was not stored consistently captured adults, but this area was connected to the main part of the warehouse that contained the stored food. Inside temperatures were above 15 °C for most of the year, while outside temperatures were consistently above 15 °C from mid-May to mid-October. Economic analyses of conducting a monitoring program were done using estimates for fixed costs of traps and variable costs for labor provided by private industry, calculating labor costs for in-house monitoring versus outside contractor costs, and comparing those estimates with the research costs of conducting the program (three different scenarios). A threshold trap catch level of two males per day was used to describe methodologies for reducing total trap numbers and associated economic costs, with minimal loss of data resolution.

1. Introduction

Plodia interpunctella (Hübner), the Indianmeal moth, is a cosmopolitan pest of food storage facilities, and can infest a variety of nuts, spices, and food products (Mohandass et al., 2007). Recent field studies have shown abundant populations of this species and other stored product insects in and around milling and processing facilities, food storage warehouses, and feed mills in the United States (US) (Arbogast et al., 2000; Doud and Phillips, 2000; Campbell and Mullen, 2004; Larson et al., 2008). Mobile adults can easily disperse from sources of infestation outside or within a facility, and focal points of infestations often shift within a storage site in the same season (Campbell et al., 2002). Immigration from outside populations, resident infestations within a site and the introduction of infested product into the facility can all contribute to infestation pressure (Campbell and Arbogast, 2004).

Pheromone trapping using the commercially available (*Z*,*E*)-9,12-tetradecadienyl acetate (ZETA) lure to attract male *P. interpunctella* can be employed to monitor population trends, identify sources of infestation, examine distribution patterns, and document the spread of an infestation within a facility (Zhu et al., 1999; Campbell et al., 2002; Nansen et al., 2008; Trematerra et al., 2011). However, it is sometimes difficult to interpret moth capture data because of various factors that affect trap performance (Arbogast et al., 2005; Nansen et al., 2008). Interpretation of trapping data is especially difficult in food warehouses because of the constant movement of commercial food products into and out of the building and among different locations within facility. Therefore, it may be more difficult to pinpoint the sources of infestation in warehouses compared to more static facilities such as mills or processing plants. Recent research has also focused on improving the efficiency of pheromone traps, through additional attractants (Nansen and Phillips, 2004), better placement of traps (Nansen et al., 2004), and new approaches to data interpretation (Nansen et al., 2008).

Although pheromone traps are widely used for monitoring *P. interpunctella* populations inside facilities, many questions

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remain about the optimal number of traps needed, where best to place traps, and how to interpret the data in regards to management decisions. Guidelines for trap placement supplied by manufacturers have not been scientifically evaluated in the literature, nor have the economics of monitoring programs and methods of processing traps. The cost of sampling for stored-product insects in bulk grains has been addressed on a limited basis (Adam et al., 2010; Yigezu et al., 2010), but there are no comparable studies evaluating pheromone trapping programs. Campbell et al. (2002) evaluated data from a monitoring study using re-sampling to assess how changing the number of traps impacted the estimated mean capture level; however; impact of trap density on labor and material costs of a sampling program have not previously been evaluated in the literature. Hence, the objectives of this study were to: 1) use pheromone baited traps to determine temporal and spatial patterns of male *P. interpunctella* captures inside and outside a food facility warehouse, 2) estimate the costs of the components of the program, including fixed and variable costs, and 3) evaluate the trapping data and economic analysis to describe how a targeted *P. interpunctella* monitoring program could be developed for a food storage facility that would minimize sampling costs while providing data necessary for management decisions.

2. Materials and methods

2.1. Monitoring study

This study was conducted in a large food warehouse responsible for storage and distribution of packaged and canned food products. This was a new site that became operational in early June of 2005, and products were moved from the former location to this new site. The warehouse was heated during the winter but not cooled by air conditioning during the summer. We began monitoring for *P. interpunctella* on 22 June 2005 and concluded the program on 4 April 2008. Traps were set out at the approximate locations shown in Fig. 1. The traps were diamond traps baited with the ZETA pheromone, both manufactured by Trécé, Inc. (Adair, OK, USA). The pheromone lures in the traps were changed approximately every 6 weeks from late spring to early autumn, and every 8 weeks during the rest of the year.

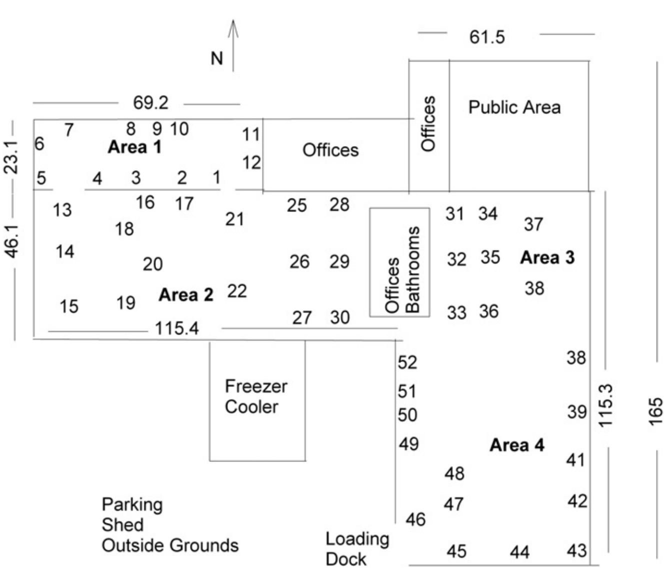

Fig. 1. Diagram showing approximate placement of pheromone traps inside each main area 1, 2, 3, and 4 within the food warehouse. All dimensions are in meters.

For analysis the food warehouse was divided into four main areas (Fig. 1). Length and width dimensions of each area are given in Fig. 1. The ceiling heights in Areas 1, 2, 3, and 4 were 10.8, 10.8, 4.9, and 3.4 m, respectively. This gave calculated volumes for Areas 1, 2, 3, and 4, of 17,264; 57,406; 22,059; and 8300 m^3, respectively. Area 1 had walls with no openings along the west and north sides, and an interior door on the east end. There were overhead doors at the southeast and southwest ends, open to the interior of the warehouse (Area 2). Area 1 contained canned goods and various non-food items such as furniture, office supplies and equipment, and shelving units. Twelve traps were hung approximately 1.5 m above the floor on beams, support cables, electrical boxes, etc. along or near walls. Traps #1–8 were evenly placed along the side walls, while the remaining traps were more clustered due to the location of stacked palleted goods. Area 2 was the primary storage area for packaged and processed food items, and had fifteen units that were about 6 m in height and 28 m long. Each unit had three levels of shelving where food goods were stored. Eighteen traps were hung underneath first level shelves, about 1.5 m from the floor, and traps #16 and #17 (Fig. 1) were hung from the electrical conduit at the same approximate height from the floor. These traps were evenly placed underneath areas where there were packaged goods on the shelves, as opposed to an evenly spaced grid placement. Area 3 was also a site for food storage with twelve shelf units smaller in height than those in Area 2 (about 3 m high), six on each side. Eight traps were evenly placed and tied to the first level shelf as described above for Area 2. The amount of packaged food goods stored in Areas 2 and 3 varied but overall it declined during the study. Thus, while all traps in Areas 2 and 3 were on shelves that contained packaged or processed food at the start of the study, some of the shelves were empty by the end of the study. Adjoining Area 3 but separated by a fixed wall on the north side was a separate room 46.1 by 36.9 m in width and length and 4.9 m in height where the general public brought donated goods and volunteers sorted those goods. There was an interior door from Area 3 into this room, which was usually closed. Areas 3 and 4 were separated by an open fence with multiple aisle openings to accommodate transfer of pallets by forklifts, but no wall. Area 4 contained no shelf units, and served as a transfer point from the loading dock to Areas 1–3. Nine traps were hung from electrical conduits, randomly spaced but in an even pattern, as described for Area 1. Four additional traps (#49–#52) were added in the second and third years of the study and placed along a back wall on the southeast side of Area 3 that separated a storage closet from the larger area.

During the summer months, traps were checked every one or two weeks, during autumn the traps were typically checked every 3 weeks, and during the winter traps were checked every five or six weeks because of limited moth activity during that time (Table 1). When traps were sampled, a new trap was substituted for the existing trap, and pheromone lures were replaced about every 6 weeks as recommended by the manufacturer. In the laboratory, male *P. interpunctella* were counted and recorded, moths were

Table 1
Total number of *P. interpunctella* trapped inside each of the four areas of the food warehouse (see Fig. 1) by year from 6/29/05 to 12/19/07[a], with the percentage of the total in each area in each year in parentheses. Number of traps in Areas 1, 2, 3, and 4 in 2005 were 12, 18, 8, 10, respectively, in 2006 and 2007 the number for each Area was 12, 18, 8, and 14, respectively.

Area	2005[a]	2006	2007	Total
1	1954[a] (16.0)	2736 (12.3)	2800 (18.5)	7490
2	6153 (50.3)	8405 (37.7)	5241 (34.6)	19,799
3	2667 (21.8)	5025 (22.6)	3782 (25.0)	11,474
4	1451 (11.9)	6562 (29.4)	3320 (21.9)	11,333
Total	12,225	22,278	15,143	49,646

[a] The first sampling date in 2005 was 6/29.