19 Insect Pest Management Decisions in Food Processing Facilities

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Making pest management decisions in food processing facilities, such as flour mills, rice mills, human and pet food manufacturing facilities, distribution centers, warehouses, and retail stores, can be challenging. Implementation of a pest management program requires an understanding of food facility structure and operations; taxonomy, behavior, ecology, and biology of pest species; and effective use of monitoring and management tools. Programs require collaboration among those who work for the food processing company and those who work for the pest management contractor. Decisions need to be made about the system as a whole, how to deal with issues before they become major problems, and how to allocate resources effectively.

The food industry has been moving away from structural fumigations and calendar-based chemical pesticide applications toward integrated pest management (IPM). This shift has been driven by the loss of products such as methyl bromide, demand for reduced pesticide usage, and targeted use of reduced risk products. Pest management and food safety practices must withstand increasingly intense scrutiny of external inspections and audits. These trends underscore the need for improvements in the pest management decision-making process in the food industry.

Traditional IPM programs, which are based on the concept of letting pest populations build to a certain point before treatment is economically justified (economic threshold), do not apply in the food industry. IPM programs must focus on prevention, detection, and early elimination of problems. IPM goals for the food industry are to prevent insects from entering the facility; to keep insect populations from increasing or becoming established in the production stream; to suppress insects where prevention has been unsuccessful; and to monitor the environment. Monitoring is an overarching component because it can be used to evaluate prevention program effectiveness and guide application of suppression tactics.

In most food facilities the goal is zero insect activity. This is seldom possible because insect management is a continuous process of responding to changing conditions and problems. Although an economic or action threshold of one insect for an entire facility is seldom feasible, effective thresholds are needed. Thresholds should be adjustable, targeted, and serve as upper boundary limits to indicate a successful program. Management programs should aim to prevent insects from reaching threshold levels and triggering an increase in intensity or change in response when limits are exceeded.

Food facilities typically are large, complex structures with many locations vulnerable to insect infestation. They differ from each other in function (food processing, mill, warehouse), commodities (wheat, rice, animal-based materials, spices), product produced (flour, whole grain, human food or pet food products), equipment, structure type (old versus new, construction material), geographic location, surrounding landscape, among other factors. This makes generalizations about pest management difficult. Facility conditions can change over time because of seasonal fluctuations, changes in physical structure and management, and other variables. The pest situation must be characterized for a given location, and an IPM program should be tailored to a specific location and flexible enough to deal with changing conditions. A rigid or standard approach to pest management is rarely successful. Although pest management is part of a food facility's prerequisite program, in many cases it can be implemented more effectively. Specific tools for monitoring and pest suppression have been presented in other chapters. This chapter will focus on the philosophy and strategies for using these tools to make pest management decisions.

Inspection

An inspection should focus on identifying the location and nature of current pest issues and on noting vulnerable areas of the facility with potential to generate pest issues. It is a physical review of a facility, both inside and out, to assess conditions at a given time and their potential to affect the food manufacturing process (AIB International 2010). Inspection also assesses operational methods and personnel practices, equipment maintenance, condition of grounds and structures, and cleaning practices that affect pest management program success. Technical information on the inspection process and types of corrective actions is provided in Chapter 8.

An inspection is the first step in implementing an integrated pest management program. Regular inspections going forward can be used to evaluate program effectiveness. The goal of the initial inspection is to identify the location and nature of current pest problems and pinpoint locations with potential for pest issues. From this, a prioritized list of issues can be developed with both short-term (immediate issue corrected) and long-term (steps to reduce or eliminate the probability of the problem reoccurring) corrective actions (Osterberg 2006, St. Cyr 2006).

Inspection is a fundamental part of a pest management program, but there are limitations. A thorough inspection requires a highly skilled person. It is hard, dirty work and requires access to areas that can disrupt production. Labor and time can limit how frequently and thoroughly inspections can be performed. Quantifying and evaluating trends in insect activity based on inspection reports can be difficult because of variation in how inspections are performed and data recorded, and limited frequency. Inspections function as periodic benchmarks of program success. They identify problems that need correction, but other monitoring methods can be more useful for trend analysis. Inspections, even thorough ones, can miss early stage infestations or those in inaccessible locations. Previous experience with a particular type of facility can help predict where inspections should be focused, but preconceived ideas of where insects are likely to be found can be wrong. Insect distribution within a facility can change over time. Problems can develop in unlikely areas (Campbell et al. 2002, Semeao et al. 2012). It is useful to supplement inspection results with other sources of information.

Exterior inspection

Because the primary goal of a pest management program is prevention, inspection should start outside the building. The goal is to identify locations with insect activity, resources near structures that can attract or be exploited by insects, and potential pest entry routes into a facility. Studies have shown high levels of stored-product insect flight activity outside food-processing and grain-storage facilities, which can represent considerable invasion pressure (Campbell 2006). Many stored-product insects are strong flyers that can easily traverse a food facility site (Campbell and Mullen 2004) and enter buildings (Campbell and Arbogast 2004, Toews et al. 2006). The purpose of exterior pest management is to make a food facility site less attractive and to make it more difficult for insects to enter buildings where food is processed and stored.

The exterior environment consists of two zones — onsite and offsite — based on insect source potential. Onsite includes the external environment that can be monitored and managed directly. It includes features within the property lines that might support or attract insects. For stored-product insects, these include spills that attract insects or provide reproduction sites, such as bulk storage, trash piles, or containers. The offsite zone includes landscape surrounding the facility that is within pest dispersal distance. Given the mobility of many stored-product insect species, movement from the surrounding area to a facility can occur. Offsite sources within a half mile of a food facility would be well within the dispersal range of many flying stored-product pests, and sources farther away are potential candidates. For example, lesser grain borer adults were captured 1 km (0.6 miles) away from where they were released within one day (Campbell et al. 2006). Identifying potential offsite sources can help guide outdoor monitoring programs and assess risk level.

When thinking about inspecting the exterior environment and preventing insects from entering a food facility, keep in mind that there are a wide range of insect species occurring outside. They vary in likelihood of entering a food facility and which exterior features are attractive to them. Most species that enter are incidental species rather than stored-product pests because they are not attracted to the food being processed and do not reproduce within the food. To visualize this abundance think of the variety of insects that can be seen around a porch light at night. These species present low risk in terms of product infestation or establishment inside a food facility but are of concern because their presence inside could lead to food contamination and adulteration. Observation of them on inbound or outbound products could lead to shipment rejection or treatment, and they indicate inadequate building sealing.

Understanding features of the environment that favor specific groups of insects can be useful in making management decisions. The type of insects found inside indicate what to look for during external inspection. If incidental species are found around doors and windows, inspection should focus on features that attract them — lights, standing water, vegetation, garbage, food spillage — and the identification of entry routes — lights over doors, interior lighting, gaps around doors and windows, and open doors. Some species are not typically pests of structures or food but enter in the fall in search of overwintering sites — for example, Asian lady beetles and boxelder bugs. These species are likely to respond to building color, shape, and temperature, not necessarily lighting or other factors. Moist environments and decaying organic material near facilities can encourage springtails, sap beetles, fungus beetles, and some fly species that move into buildings.

Stored-product insects are less likely to be attracted to the same features of the landscape as incidentals. They are more likely to respond to food odors associated with external spillage of whole grain or processed materials, bulk stored grain, blown out material, and exhaust vents. Linking the biology of insect species captured indoors with attractive features of the external environment can help to target inspections and prioritize exterior features for improvement.

Food accumulations outside are the most obvious reason for stored-product insect activity. Although grain spillage in elevators has been shown to have a diverse community of stored-product pest species associated with it (Arthur et al. 2006), much less is known about the role of exterior spillage accumulations in maintaining or increasing stored-product insect populations. This role likely depends on how quickly degradation by environmental factors such as rain reduces the quality of the resource.

Even without reproduction occurring in them, spillage accumulations are problematic because they can attract stored-product insects that use them as stepping-stones to move into a facility. They can also attract birds or rodents. Semeao (2011) found that capture of walking stored-product insects outside of food processing facilities was not strongly associated with spillage piles, but in some cases fungal-feeding species were more likely to be associated with these outside spillage accumulations. The fact that these same fungal-feeding species are often captured inside relatively dry environments such as flour mills suggests that accumulations may serve as a source of these types of insects. Although cleaning spillage is important for a variety of reasons, the relative importance of different types of food accumulations as stored-product insect reproduction sites needs further evaluation.

Response to an inspection reporting spillage accumulation might include several steps: 1) take samples of food material and inspect for insect activity or place traps in area to capture walking insects; 2) implement short-term response of cleaning or insecticide treatments (if insect activity warrants); and (3) implement long-term solutions such as regular cleaning, structural modifications to eliminate or reduce accumulations, or modifications such as paving to make spillage easier to clean and less favorable for insect development.

Inspection of the building exterior should focus on features that may be attracting insects and enabling them to enter. These may involve building features (lighting placement, location of doors and windows, wall construction), structural defects (cracks or holes in walls or screens), or employee practices (open doors or windows, materials stored adjacent to building, poor sanitation). The roof is an area that is easy to overlook but needs attention because of numerous entry routes such as passive vents, air intakes, and poor membrane seals. Spillage accumulations can occur on roofs due to location of exhaust points, and insect pests can fly and walk up to these roof areas.

Most stored-product insect species are small enough to move through narrow gaps, so it is not possible to make a building insect proof. Inspectors should evaluate tactics used to prevent entry around identified access points, such as screening, gaskets and seals, air curtains, and door-opening policies. The effectiveness of these tactics can be assessed by monitoring insect activity in these areas. Glue boards or screening coated with the material used in sticky traps and placed around suspected entry routes can be used to determine if the routes are being used by insects (Toews et al. 2006).

Internal inspection

Interior inspection follows the same general principles as external inspection. The initial inspection identifies problems and evaluates the effectiveness of management practices. Regular inspections provide feedback on program success and identify issues as they develop. The components of an inspection program specific to stored-product insect management are the identification of structural features and activities that enable insects to enter a building, those that provide resources that can be exploited, and identification of locations with current insect activity. Inspection programs can reveal a long list of issues that need to be addressed. The challenge becomes how to prioritize issues because time, labor, and money to deal with all issues immediately typically is not available.

The nature of the problem determines priority. Actual signs of insect infestation should be high priority for short-term responses. The species detected, numbers, and developmental stages (adults versus immature stages) and whether activity is in a critical area, should be considered in making decisions on the timing of the response Prioritizing and implementing both short- and long-term solutions to items identified in an inspection program can facilitate an orderly response to pest management.

In evaluating locations where insects might occur, it is important to consider the biology of the important pest species likely to be found in the particular type of facility or those that have been an issue in the past and kinds of resources they will exploit. Inspection programs for stored-product insects established within a food facility should focus on four areas: bulk or packaged raw ingredients, processing equipment, building structure, and bulk or packaged finished product.

Insect activity in different areas may be connected but vary in product infestation risk and management tools available. For example, some locations are not accessible while the facility is operational, and some insecticides cannot be applied to food handling surfaces or finished product. Different areas within a facility can harbor different pest species, and pests can vary in the likelihood of moving from one area to another. For example, species that feed primarily on whole grains may be found near bulk storage areas for raw grain and near grain cleaning areas, but often do not move into food processing areas. Other species may be present within a building structure, but are rarely found associated with the finished product. For example, Indianmeal moth and almond moth can be observed inside mills but are seldom found infesting processing equipment.

Determine Pest Critical Control Points

Hazard Analysis Critical Control Point (HACCP) and other standards are used to identify potential food safety hazards and implement procedures to reduce or eliminate hazards before they occur. As part of this process, critical control points are identified where physical, chemical, or biological hazards to food safety can be targeted in the most effective manner. HACCP is ultimately part of a multicomponent process, which also includes Good Manufacturing Practices (GMP) and Sanitation Standard Operating Procedures (SSOP). While contamination by insects is not considered within HACCP programs, the steps involved in implementing a HACCP program are relevant to developing pest management programs: monitoring, verification, and validation. Monitoring involves making observations or measurements and assessing program needs to determine if problems are under control, and producing accurate records of monitoring results. Verification evaluates whether monitoring tasks are in compliance with the program and is conducted by reviewing records and onsite conditions. Validation determines if the elements of the program are effective at controlling hazards and is assessed either through review of literature or regulations or through actual validation studies.

The HACCP process can be applied to thinking about pest management decisions in food facilities such as where to place monitoring devices and target management tactics. For example, what are the critical areas within a facility where pest activity will cause greater risk of food contamination? What are the critical control points in preventing insects from entering a facility? The emphasis should be on assessing pest risk level in these areas and putting specific procedures in place to respond to pest activity. Responses should be location and pest specific. Monitoring is also used for verification and validation of overall pest management program success.

As with HAACP, verification involves the review of monitoring and pest observation data and inspection of onsite conditions. Because conditions may not be stable and changes can be implemented (for example, changes in structural modifications, sanitation programs, or manufacturing process), critical areas may change, creating a need for regular assessment. Validation means that personnel should keep up to date with advances in pest management and continually assess how well the program is working or if it could be improved. New information such as consumer complaints, increasing numbers of insects, or presence of a new species at a location should be evaluated to see if adjustments to the program are needed.

Each food facility has specific areas that are either more vulnerable to pest activity or where pest activity will have greater negative impacts. Identifying them and developing inspection, monitoring, and management programs that emphasize these areas can improve program effectiveness. Locations where potential for product infestation is greatest such as packaging areas, zones where inbound and outbound product is stored, locations where insects tend to be found the most frequently, and locations with favorable environmental conditions for insect growth such as high levels of spillage or higher temperatures could all potentially be critical control points.

The goal is to place the emphasis of the IPM program in areas where limited resources can be applied with the greatest benefit. Focusing exclusively on these areas can lead to problems because insects can develop in a wide range of areas within a food facility. Without inspection and monitoring in all areas, pest populations can be missed until levels develop to the point where control is more difficult and the insects disperse into critical areas. For example, dispersal of warehouse beetle from a shutdown portion of a food processing plant resulted in high activity levels within the finished product warehouse, where fumigation and aerosol insecticide applications were not effective (Campbell et al. 2002). The idea is not to focus exclusively on these critical areas but to give them greater emphasis and priority. In noncritical areas, less frequent regular inspections and lower densities of traps for monitoring relative to critical areas might be appropriate.

Monitoring Program

Monitoring is the regular surveillance of insect activity over time. A wide range of monitoring tools and tactics are available for monitoring insect activity in bulk grain and in food processing facilities. The type of monitoring program implemented should be aligned with the goal(s) of the IPM program. No single monitoring tactic will supply a complete picture of insect activity at a food facility. Multiple approaches should be used and results integrated. Traps baited with pheromone or food (kairomone) attractants are the most widely used monitoring device for stored-product insects in food facilities with a wide range of commercially available traps and attractants available (Chapter 21). The benefits and limitations of pheromone-baited traps are discussed elsewhere. The focus here is on how to use these types of devices to make management decisions. Results of other types of trapping devices such as light traps and sticky cards can be used in similar ways.

When making decisions from monitoring program data it is useful to keep in mind the differences between direct or indirect sampling methods. In direct sampling, insects are accurately counted and expressed as numbers per unit of measureable physical area or food material. Direct sampling methods include inspection and insect counting in food accumulations within a structure or piece of equipment, sampling food material as it is moving (e.g., counting insects in tailing samples from milled products), and sampling of static materials such as stored grain sampling or product sampling. These measures give a direct assessment of whether a sample of material is infested or what the insect density is in a given amount of material. In food processing facilities, small sample sizes and inability to sample all the locations that can be exploited can reduce the effectiveness of these approaches. Indirect monitoring in a food facility typically involves the use of some type of trap to capture adult insects moving through the facility. Some of the difficulties in interpreting trapping data are discussed in Chapter 21.

Trapping program data currently is best used by comparing the relative levels of capture among locations and over time, because it is difficult to relate captures back to actual insect density or source of the beetles. In food facilities, most of the insect population is hidden in refugia that are difficult if not impossible to sample, and traps primarily capture adults that leave those locations in search of new resources or mates. For example, a large set of data from a variety of laboratory experiments evaluating red flour beetle populations in small amounts of flour indicated that overall the percentage of adults was less than 15% of the total population (Campbell, unpublished data). Considering that only a percentage of these adults are dispersing outside of these hidden refugia at a given time and that there can be a delay while populations build before adults disperse, it becomes obvious that traps can only reflect a small amount of the insect activity in a location. Despite these limitations, trapping programs can provide valuable information if used correctly.

Implementation of monitoring programs

Strategies for using pheromone traps or other types of monitoring devices used in a pest management program fall into two types. The first strategy is to use them as a detective tool for early detection, determining the presence or absence of a problem in a critical control point and to assist in finding foci of infestation to be targeted. The second strategy is analysis of trends over time in either focused problem areas or as a more widespread monitoring program throughout the facility. Overlap between these strategies exists, and they should be integrated.

When traps are used as a detective tool it is typically in response to some sign of insect activity, for example, infested product or spillage, insect tracks in dust, or a hot spot in pheromone trap captures. The objective is to identify the scope and source of the problem, and traps can be used in combination with inspection. Traps can be placed in a grid in the area suspected of insect activity or placed in a transect going out from the suspected problem. This use of pheromone traps is typically in response to an observed problem, although a hot spot in insect captures in a trap, especially if placed at a critical control point, can also be used as a trigger for more intensive follow-up monitoring to prevent problems from growing and spreading.

Because hot spots of insect activity could be due to a localized infestation that can be identified and removed or because insects have moved into this area from some other source such as via an entry route from outside, visual inspection should also be part of the program. After some intervention such as sanitation, structural modification, or insecticide treatment, the traps can be monitored to determine the effectiveness of the response. If the problem is solved, then the focused trapping program typically is removed. This strategy is a dynamic process that is useful for identifying and eliminating established pest problems, but it does not quantify pest activity in a way that can be used to document and evaluate the long-term impacts of management programs. Data from a flour mill shown in Figure 1 can be used to illustrate how traps can be used as a detective tool to aid management decisions, while also being used for trend analysis. On one floor, red flour beetle captures appeared to be centered at primarily a single trap location, and with subsequent inspection it was revealed that the gap between the top of a piece of equipment and the ceiling was an area where flour accumulated and an infestation had become established. Beetles dropped to the floor in this area, and then some were captured in the trap. Removal of material and inclusion of the location in a regular sanitation program eliminated the problem as indicated by subsequent monitoring.

The second strategy is to use a pheromone trapping program to evaluate trends in pest abundance and the overall success of an IPM program. To implement this approach a standardized monitoring program is needed that generates information that can be accurately compared over time. Maintaining a consistent trapping program, with traps similar in number and position from year to year, enables ongoing capture patterns to be more accurately compared. Generated data can then be used to calculate the average trap capture and to graph trends over time. Trap data can be used to look for differences in pest abundance and distribution in different areas, determine seasonal patterns in activity, and look at spatial patterns in distribution to identify problem sources and enable early detection. Through better understanding of the patterns, realistic management goals can be developed and the success of the programs determined. For example, multiple years of red flour beetle pheromone trap monitoring data (Campbell et al. 2010a, b) was used to evaluate the impact of structural fumigations on reduction in captures and how quickly captures rebounded after treatment. This provided baseline information on what efficacy should be expected and whether a new fumigant is giving results in line with previous experience at the mill. These long term trends can also be used to evaluate how an enhanced pest management program impacted pest abundance since average capture the year before and the year after making the change could be compared.

Evaluating long-term trends in outside monitoring can provide valuable information in assessing the role of immigration from outside to determine whether increases in activity inside might be related to seasonal patterns in regional abundance of the insects (higher captures overall outside) or are associated with an outside source that is producing more insects (e.g., bulk storage area). For example, in a flour mill Indianmeal moth captures in traps cycled with the season, and fumigations of the structure appeared to have little influence on the captures. This would seem to suggest that the fumigations were not successful, but comparing the trends inside with

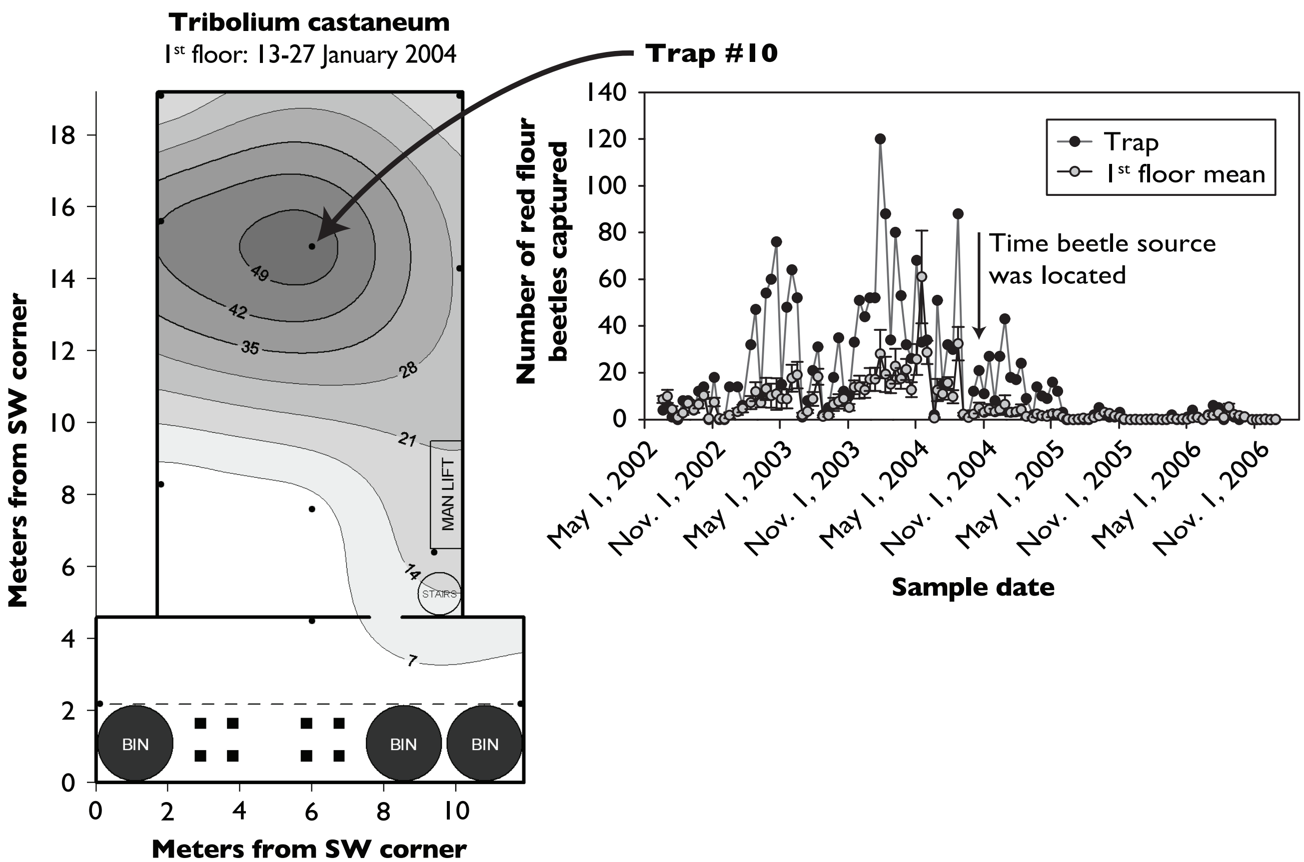

Figure 1. *A hot spot of red flour beetle activity was detected at location of pheromone trap #10, which had consistently greater captures than the average for the floor. Finding and eliminating the source population and including location in a regular sanitation program resulted in consistently lower captures.*

those outside revealed that inside captures were likely recent immigrants from outside. Coupled with little evidence of establishment inside based on inspection, it was concluded that the fumigations did not appear to impact populations because only actively dispersing individuals were affected and these individuals were quickly replaced after treatment (Campbell and Arbogast 2004).

The potential for outside monitoring to increase insect attraction to the site and to increase attraction into a building if traps are placed near doors is an issue raised by companies and pest management professionals. No data documents that pheromone traps increase attraction to or immigration into structures. It appears unlikely given that food odors from a site are more important in attracting females, which is the sex that will initiate infestations. Most pheromone-baited traps use sex pheromones that only attract males that cannot establish new infestations. In addition, captures of stored-product insects outside food facilities or elevators can be high even without pheromones in traps (Dowdy and McGaughey 1998) and the long-range attraction to pheromone is likely to be limited and would attract only insects that are already in the vicinity (Mankin et al. 1999). At a wheat seed warehouse, a wide range of insect species were captured coming in around overhead doors, while only pheromone traps for lesser grain borer were placed inside the facility (Toews et al. 2006). Because in most cases it is not known how many individuals are entering buildings normally, it is hard to determine the size, if any, of an increase due to pheromone use. If as assumed traps do not increase outside activity, then every stored-product insect captured outside is one less that could enter the facility. As with all monitoring it is a trade off of cost versus benefit. Is it better to have no measure of insect levels outside a facility and spend either insufficient or excessive amounts of time and money on exclusion, or to eliminate the risk of any increase in immigration that might be associated with outside trapping?

Reporting and interpreting results of monitoring programs

It is becoming increasingly important to have documentation that a monitoring program is in place. As a result, the number of facilities conducting pheromone trapping programs has been increasing over time. In many cases the full benefits of a monitoring program are not being realized. Because pests are not evenly distributed at food facilities, in addition to evaluating overall trends in data over time, there are advantages to evaluating spatial distribution of pests.

As discussed in Chapter 21, a wide range of methods are available for evaluating the spatial distribution of pest species, although there are limitations to where different methods can be applied. Data presented graphically rather than as tables of numbers is a more intuitive way for many people to understand patterns, which is why methods such as contour maps are popular. For example, in Figure 2 contour maps can make it easier to identify areas with greater activity in this warehouse. In this example higher areas of warehouse beetle capture appear to be associated with doors (suggesting an immigration problem due to poor sealing or closing of doors) and near pallet wrapping equipment (perhaps a localized infestation), while for Indianmeal moth it is primarily around the doors. Accurate contour maps require a relatively large number of traps and good coverage of the area being evaluated, which can limit their application. Care should be taken in interpreting contour maps because they are mapping only the distribution of adult captures in traps, and not the actual distribution of the population, including both males and females along with the different life stages (eggs, larva, and pupae) within the facility. Contour maps also can be vulnerable to distortions when the assumptions behind their calculations are not supported. Contour maps can be used cautiously to guide the targeting of follow-up inspection. Changes in distributions over time can also be evaluated by comparing contour maps created at different times or by creating contour maps of the change in capture from one monitoring period to the next.

In situations where a facility consists of multiple floors, separated rooms, or large facilities with low densities of traps, contour mapping becomes more difficult. Many facilities consist of multiple buildings and outside traps that also make the construction of contour maps more difficult. Other approaches such as use of bubble plots can be used in these situations. Figure 2 shows the same data presented as both contour maps and as bubble plots. Bar graphs of numbers captured in individual traps can also be used to visualize patterns in distribution. For example, in Figure 3 captures of predominate species in individual traps is presented as bar graphs. This approach can provide a quick overview of the whole facility as well as help in identifying individual trap locations that have higher captures that might be targets for additional inspection. Changes in distribution over time can be evaluated by comparing graphs created from different monitoring periods. Sorting and grouping data in different zones also may help with viewing and interpreting the data generated from a monitoring program. In this rice mill example four zones were created (two rice storage areas, mill, and outside) and color-coded in the original graph. These areas tend to have different species present and are managed differently so they make useful groupings. This approach can be easily customized to a given facility. Averages for the different zones can be calculated and compared over time.

For trend analysis of a food facility as a whole or for specific areas within a facility, line graphs and tables can be useful in consolidating the information generated from a monitoring program. Trend analysis is important for several reasons. Many pests have seasonal patterns in activity in traps and trends upward and downward need to be placed within this context

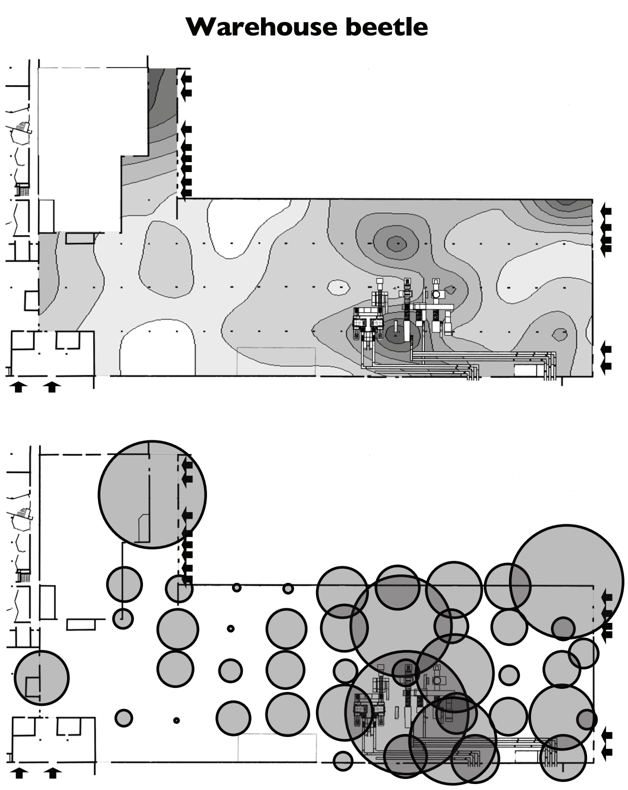

Figure 2. *Top row: contour maps of the distribution of captures of warehouse beetle or Indianmeal moth in traps within a food processing facility warehouse (the darker the color, the higher the captures). Bottom row: same information presented as bubble plots with the diameter of the circle proportional to the number caught. The arrows indicate doors to the outside.*

before decisions should be made about treatment. Comparing trends in different zones can provide insight into the sources of the insects. For example, as discussed earlier, similar seasonal trends both inside and outside of a food facility suggests that immigration from outside areas may be an important contributor to pest activity in the facility. The converse, trends for populations to increase or cycle independently of outside activity, can indicate an established population within a facility.

Analysis of trends can be done for individual species or for functional groups of insects such as whole-grain feeders, stored-product moths, incidental insects, or flies depending on the level of precision needed. Trend analysis enables thresholds to be developed that trigger responses as discussed below. Trend analysis is important for evaluating the effectiveness of specific treatments or changes in management programs. Seldom can the effectiveness of a treatment such as sanitation, aerosol insecticide application, or structural modification be determined based on a single period of monitoring. To determine impact, long-term trends typically need to be evaluated or compared to trends in previous years. For example, cleaning programs can disturb insects and increase the capture in traps for a period of time after intervention. Increasing the level of sanitation or the frequency of aerosol insecticide applications will have a gradual impact on reducing pest populations, which can take months to years to fully evaluate. For example, in a rice mill the trending data on red flour beetle captures over the period of two years could be used to help assess whether the implementation of an aerosol insecticide program is having a suppressive effect on pest populations (Figure 4). This is a useful approach, but care needs to be taken because pest activity can change over time for reasons other than the change in treatment. In this example, there is evidence to suggest that change in the program is keeping pest levels below a threshold value that could be used to trigger additional pest management interventions. Information should be confirmed by evaluating multiple years and using other measures of pest activity such as inspection.

Establish Action Thresholds and Responses

In manufacturing, the production of product is monitored to ensure tolerances are being met. This is a critical component of quality control programs. This process involves establishing thresholds for what is considered a quality product, conducting regular measurements, and evaluating trends and implementing a specific set of responses if threshold values are exceeded. Ideally, this same process should be applied to pest populations in food facilities and the assessment of the quality of a pest management program. Levels of pest activity detected should trigger specific responses in terms of either additional monitoring and inspection to identify the foci of the problem or application of additional management tactics to solve the problem both in the short- and long-term.

Simply collecting monitoring data and storing it in a folder to document that a program is in place is not sufficient to have an effective management program. The challenge for developing thresholds in the food industry is that relating measures such as number captured in traps to an economic impact is usually not possible, so developing economic thresholds as used in field and orchard situations is not possible. Even action thresholds are somewhat different because in a food plant a baseline level of tactics is already in place, i.e., sanitation, residual insecticide application, and structural modification. This is because programs are focused on prevention. Thresholds must be developed to determine if there is breakdown in prerequisite programs. Levels below this threshold can indicate a successful program and meeting quality standards. Exceeding this threshold level should trigger additional responses because it would indicate some sort of problem in the program.

Unfortunately, there are limited scientific data and analysis on what trap capture levels mean and how best to respond to specific levels. These levels are also likely to vary considerably with type and location of a facility. Some companies have adopted thresholds of insect capture that trigger specific actions based on historical trends in the data such as the average level captured in previous year or levels of capture

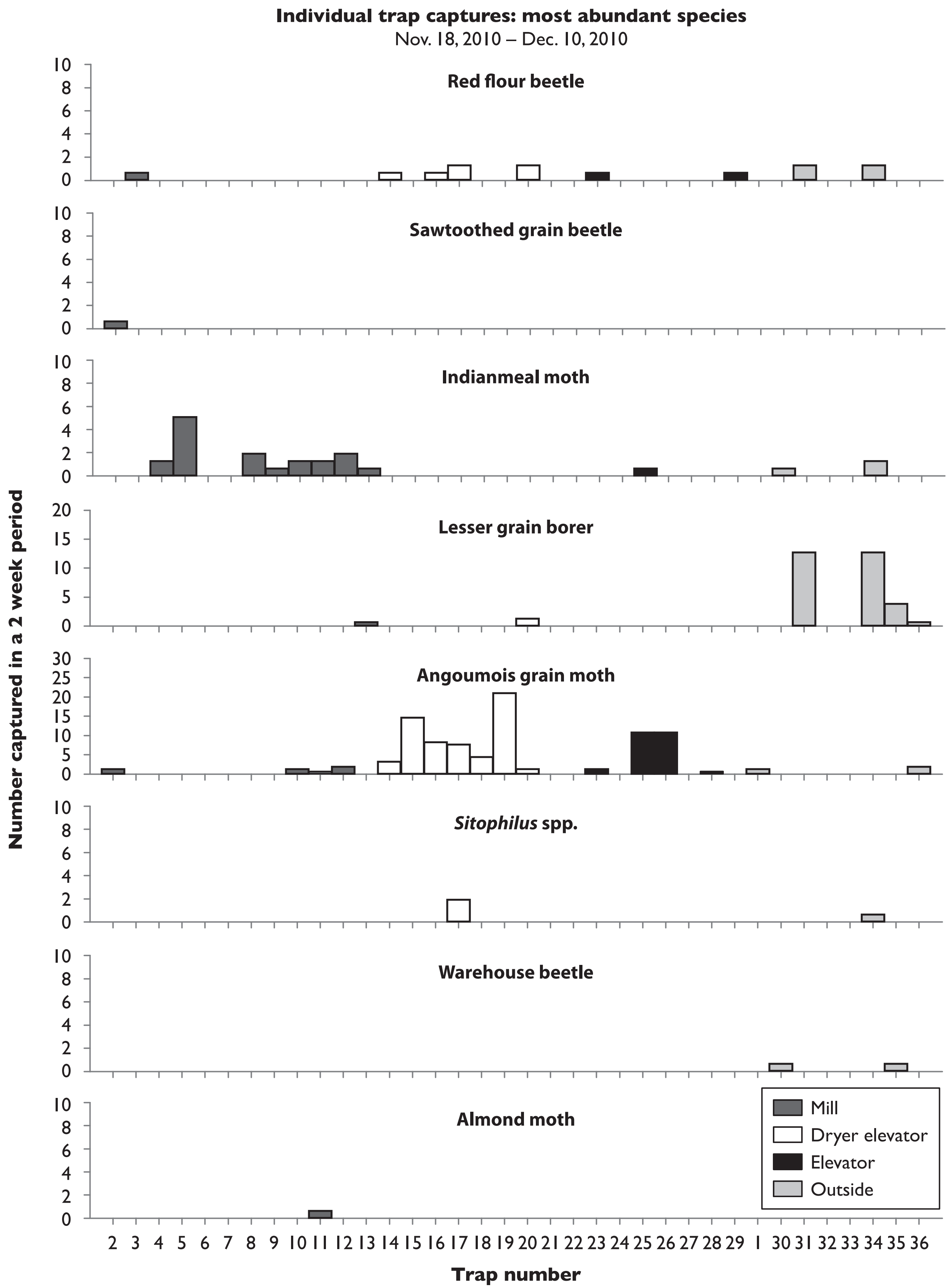

Figure 3. *Captures of stored-product insects at a rice mill represented in a bar graph of individual trap captures and the trap locations sorted into different zones.*

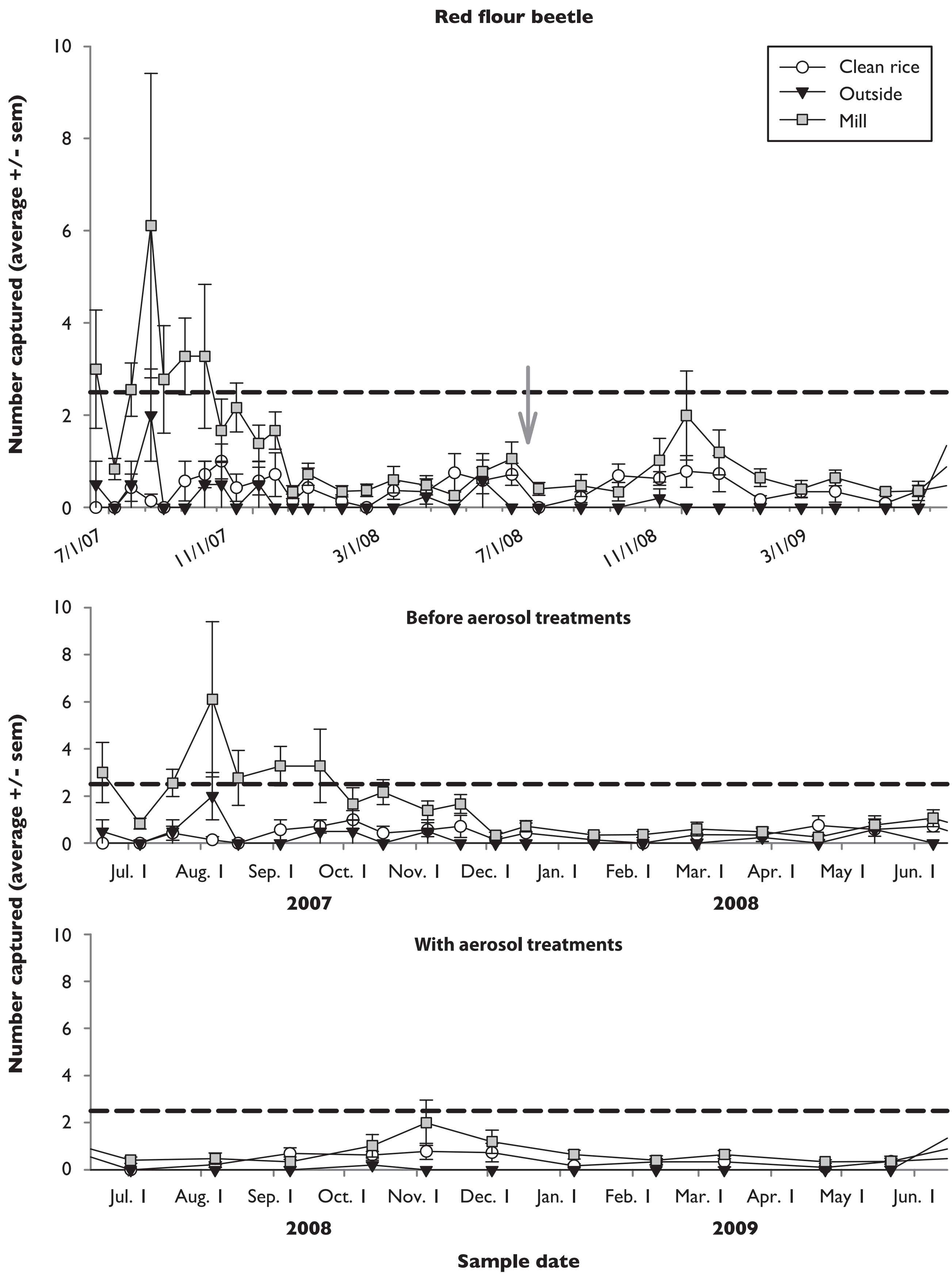

Figure 4. *Trend analysis of average capture of red flour beetle adults in three different zones of a rice mill before and after the implementation of an aerosol insecticide program involving regular applications of pyrethrins and methoprene insecticide. Dashed line indicates a potential management threshold value and the arrow indicates date mill was fumigated.*

that were associated with product infestation issues. In other situations these initial threshold levels may be relatively arbitrary and can be considered as starting points or goals and these can be refined as needed over time. For example, one approach might be to use the average number of a certain insect pest species trapped from last year as a target for the current year, with goal of keeping levels below this average in the current year. This will result in a new, lower average that can then be a new target. Levels can be adjusted to specific areas or buildings because capture levels that indicate a failure in the program and trigger an additional response may be lower in critical control points than in less critical areas. These action thresholds can be as low as one insect captured in certain situations. Action thresholds could also be triggered based on outside monitoring because as outside activity increases, invasion pressure also increases. Exclusion programs may need to be stepped up and personnel reminded about keeping doors and windows closed or screened.

Thresholds should be easy to calculate and to understand; measures such as individual trap captures above a certain level or mean trap capture for a facility or zone within a facility are reasonable measures to use. These values should be adjusted to a standard trapping interval, because sometimes traps are in place for different periods of time. Not adjusting the numbers can lead to over or underestimating pest levels and makes comparisons difficult. Action thresholds based on single traps should focus on determining the location and extent of the pest infestation and implementing a precision IPM program that will be targeted at that location to prevent the spread of the pest to the whole facility. Measures based on the whole mill will in turn give an assessment of the overall program success, with targeted response depending on identifying the specific trap locations that are out of line with the overall pest level. Proportion of traps with captures also can be used as a measure of how widespread a pest population is within a facility, and thus provides different information than mean capture data.

Campbell et al. (2010b) recently developed a risk threshold for red flour beetle in flour mills based on the likelihood of a large increase in average capture in the next monitoring period. This approach was based on the assumption that large increases in average number of beetles captured from one monitoring period to the next are likely to be associated with greater risk than when the average trap capture is unchanged or has a small increase. Large increases in captures from one monitoring period to the next may be related to a problem that is more difficult to control, increased insect dispersal associated with increased captures in traps could lead to greater infestation of products, and higher insect captures can reduce effectiveness of treatments (greater captures prior to fumigation resulted in greater numbers captured after treatment).

Analyzing a large data set from two commercial mills it was determined that 2.5 red flour beetles per trap per standardized two-week monitoring period was a reasonable threshold. Below this value trap captures tended to be stable from one monitoring period to the next, and above it they tended to increase. Preliminary analysis at other types of facilities suggests that this threshold relationship holds in other types of food facilities for red flour beetle, but further evaluation is needed into whether this approach can be applied to other insect species. It was determined that when red flour beetle captures in traps at a flour mill were above this threshold, the average number of beetles in the product samples was significantly greater than when trap captures were below the threshold. There may be a relationship between this easy-to-measure metric of insect activity and the potential for product infestation.

The risk threshold value described above may be useful as a starting point for red flour beetle management because it is the first value based on some documented potential risk. Although this level of capture may be too high as a practical action threshold and a given mill may choose a lower threshold as a management target, these values could still have practical benefit in serving as an upper limit threshold. Indeed, it might be desirable to use multiple threshold levels that trigger different levels or intensity of response. In Figure 4, the dashed line indicating the 2.5 beetles per trap per monitoring period threshold is used to show when beetle captures in traps exceeded this level.

Pest Management in Response to Monitoring Information

Although the number of chemical tools available for pest management is limited and may be decreasing, a wide range of chemical and nonchemical tools are available for managing pest populations, especially when the focus is on prevention rather than trying to eliminate populations after they have become established. Specific tactics to avoid the establishment of pests, reduce or eliminate pest populations and movement of individuals, include sanitation and structural modifications (Chapter 8); aerosol, surface and crack and crevice insecticide applications (Chapter 9); structural and commodity fumigations (Chapter 14); heat treatments of structures or equipment (Chapter 15); and resistant packaging (Chapter 12), among other tactics. There is not a single management tool that can be applied to every situation. Even structural fumigations, which are often thought to completely eliminate pest problems, seldom appear to result in pest-free structures due to either survival or rapid recolonization. Using fumigations as a last resort, and relying instead on targeted treatments of localized problems identified early using a monitoring and inspection program to prevent them from increasing and spreading should result in both a more effective and ultimately more economical strategy.

When evaluating what tactic(s) to include in a pest management program and which specific tactics are warranted in response to a problem, the decision process must emphasize which tactic will be the most effective, safest, most economical, most targeted, and least disruptive. Using monitoring and inspection tools to find the source of the problem and to define its scope can assist with the process of deciding on a management tactic. Permanent solutions such as sealing and structural modification often will be the most effective responses. Simply finding an area with pest activity and spraying insecticides often is ineffective, especially if the insecticide is not getting directly to the hidden refugia the insects are exploiting.

Part of implementing a pest management tactic is to evaluate its impact. It may be necessary to evaluate impact over a long period of time to fully determine the consequences of a treatment. In most cases there is an immediate impact, and then there is the time it takes for the problem or the pest abundance to reoccur. The rebound or recovery of pests after treatment is a process that can be managed through tools such as sanitation, temperature manipulation, and residual insecticides.

Care should be taken in evaluating effectiveness of treatments, especially pesticides, because the response that can be observed may not accurately reflect the true impact on the pest population. Adults can make up a small percentage of an insect population, even though this may be the most visible developmental stage. In experimental warehouses it has been shown that insecticide applications can result in large numbers of dead adults being observed and reductions in beetle captures in traps, but no corresponding decrease in the total pest population within hidden refugia (Toews et al. 2009). Relying only on adult activity and the perception of mortality levels based on observing dead adults can be misleading. This finding also highlights how multiple sources of information on pest activity are needed to evaluate impact of treatments.

Conclusions

A wide range of monitoring and management tools are available for stored-product pest management in the food industry. The difficulty is how to best integrate various tools into a coherent and effective program within the constraints imposed by maintaining the operation of a food production and storage facility and the production and maintenance of a quality food product. Effective programs should be knowledge-based, flexible, and developed for specific features of a given location. In this chapter, we have reviewed tools and approaches that can be used in the development of effective IPM programs.

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