21 Trapping and Interpreting Captures of Stored Grain Insects

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Overview

This chapter provides an overview of insect trapping and interpretation of trap captures for stored-product protection in bulk grain, food processing, and retail environments. The use of traps for detection, monitoring, and population estimation requires considerable knowledge of insect biology and appropriate trap use. Trap use is essential for development of meaningful integrated pest management programs. ??based on insect ecology and behavior rather than formulas for number of traps and fumigation triggers. No universal recommendations exist for insect trap use.

Practical, economic, and ecological considerations require experimentation before pest managers can decide how to implement a trapping program in a given facility. Pest managers should understand appropriate use and operation of trapping programs and be aware of common problems in commercial facilities. This chapter covers traps and attractants, factors that influence captures, and practical tips for managing a trapping program. It concludes with a discussion of how to interpret and use insect capture data.

Why use traps?

The objectives of insect trapping programs in stored product protection are to document presence or absence of a particular insect species, monitor changes in species composition, and estimate changes in insect density over time or space. Data from trapping programs are used to justify changes in pest management practices or to investigate the efficacy of a particular treatment. Trapping data should be used to complement ongoing pest management inspections, not to replace them.

While visual inspections of warehouses and stored products are important, they are qualitative and difficult to use as basis for decision support. Visual inspections alone may not provide sufficient information about emerging insect pest problems. Pest management professionals conduct visual inspections with the expectation that a particular insect pest species will be observed, if present. The technician should also be looking for dead insects and evidence of insect activity, such as trails in flour or damaged food products.

Stored product insects often are sedentary during the day and active at night when they search fors food, mates, and shelter (Toews et al. 2003). Campbell and Hagstrum (2002b) showed that only 6% of red flour beetles were moving at any given time. Continuous trapping of insects (beetles, moths, and psocids) or arachnids (spiders, mites, and predatory mites) during a two-week period provides more information about insects present than an estimate based on visual inspection. Traps can also show the absence of insect activity, precluding the need for pesticide application or fumigation.

Trap use and interpretation of insect captures provide the foundation of integrated pest management programs and may be considered a method of sampling the insect population. Sampling can be categorized in two ways. Direct sampling is defined as enumeration of insects present per defined unit of space or volume of a particular commodity — for example, counting the number of Indianmeal moth larvae in a single box of breakfast cereal or the number of beetles in a grain sample. Although direct sampling methods provide the most reliable estimates of insect density, it is unrealistic to use them with finished goods, because products cannot be sold with adulterated packaging. Direct sampling for insects that accumulate in cracks and crevices is not feasible, nor is it likely that a manager could identify every single insect harborage. Indirect sampling is any method of capturing insects or estimating damage that is not directly tied to a unit of area, volume, or weight. Trapping is considered indirect sampling because it is not known from how far insects were drawn into the trap. Insect trapping programs can be operated in all types of commercial storage, processing, warehousing, and retail establishments without jeopardizing product appearance or customer confidence.

Adoption of a trapping program may present challenges that require personnel training and education. For example, traps are frequently swept up, damaged, and discarded by custodial crews. Workers sometimes view traps as garbage that prevents them from maintaining a high level of sanitation within the facility. Trapping devices may be tampered with (example: removal of glue boards) because personnel are concerned that third-party auditors will use trap captures as part of their assessment. Similarly, some insecticide applicators view traps as unimportant, mistakenly believing that spraying a residual insecticide precludes the need for follow-up assessment.

Pest management professionals and employees must continuously improve their interpretation of trap captures and insect identification skills. Even when insects are correctly identified and reported, client reaction to new knowledge of insects present can be difficult to manage. While managers are usually aware of the most economically important insect species, managers may have less knowledge about predators, parasitoids, and fungus feeding species. Traps will inevitably show presence of these and other species that are not economically important, such as antlike flower beetles or ground beetles. Some clients may feel that presence of any insect at any density justifies intervention. They may need to be educated about economically important species, economic thresholds, and economic injury levels.

Ironically, the use of traps can make it difficult for pest management professionals to justify their efforts because contracts are often based on application frequency and linear feet of insecticide applied. Some clients may not perceive they are getting the same level of service if the pest management professional spends more time servicing traps than spraying insecticides. In these cases it is important to articulate a shift, from calendar-based spraying without regard for insect presence, to monitoring followed by targeted interventions at an appropriate time and place. A contract between a food facility client and a pest management professional should specify that insect infestations will be suppressed, even though the technician may not need to spray on every visit. Insect pest management should not be based only on insecticide treatments, but also on prevention (for example, reducing the likelihood of pests entering the food facility), sanitation, monitoring, evaluation, and possibly educational programs to the client.

Types of Traps

Interest in and availability of commercially produced traps for capture of stored product insects in grain storage and food-processing facilities has never been greater. New trap designs are continuously being introduced. Traps intended for stored product insects generally fit into four categories: light traps, aerial traps, surface traps, and bulk grain traps. It is important that pest management professionals understand uses and constraints of each type of trap to select a model that is appropriate for the species of interest. To provide usable data, traps must be durable, easy to service, and adapted to the environmental conditions where the trap will be deployed (Barak et al. 1990). In most cases, the decision on which trap to use is heavily influenced by price, and it is important to recognize the importance of having as many trapping stations as is feasible.

Light traps are wall-mounted, corner-mounted, or ceiling-suspended traps that utilize ultraviolet light (315 to 400 nm wavelength) as the insect attractant. The principle of operation is that flying insects are attracted to the light and are captured or killed when they enter the trap. Traps typically have a low current immobilizing electrical pulse or an electrocuting grid around the light source to kill insects, and replaceable sticky cards to hold the insects (Figure 1). Located above the line of sight, they are commonly used for fly control in food preparation and pharmaceutical production facilities. Some models look like normal light sources and can be mounted discretely in canteen, office, and reception areas where presence of flying insects is a sensitive issue.

Light traps attract a wide variety of adult stages of flying insects, including stored product insects, but have limited utility for detection and monitoring of key economically important stored product insect species. Nualvatna et al. (2003) found that light traps were useful for capturing Angoumois grain moths, lesser grain borers, maize weevils, and red flour beetles in rice mills and paddy seed stores. Hagstrum et al. (1977) found that the rate of female almond moth captures increased when a black light was included on the trap compared to separating the lamp from the trap; no differences were observed for male almond moth captures. Care should be taken when mounting traps. For example, traps placed near doors could attract nuisance insects into the facility. Broce (1993) warned that traps should not be located above production lines where insect parts or debris could fall into the product. For proper performance, light traps should be cleaned frequently and light bulbs replaced every 6 to 12 months.

Figure 1. *Example of an electrocuting light trap.*

Aerial traps are intended to capture flying insects, which are attracted to the trap by a pheromone lure or food attractant, then become entangled in a sticky coating or are collected in an escape-proof chamber. Rather than being placed on a flat surface, traps are suspended in the air from poles, conduit, structures, or equipment. This category includes bucket traps, funnel traps, and any of the sticky traps made of laminated cardboard coated with a sticky material (Figure 2). Aerial traps are intended for capture of adults of a few specific economically important species. Hagstrum et al. (1994) used aerial traps for early detection of insect activity in bin headspaces. When properly baited with a pheromone lure, aerial traps are effective at capturing adult moths. Examples include Indianmeal moth, Mediterranean flour moth, raisin moth, tobacco moth, almond moth, and beetles, including the warehouse beetle, cigarette beetle, and lesser grain borer. Bucket and funnel traps are much more durable, but they are larger and require an insecticide impregnated strip in the collection reservoir or a liquid to prevent escapes. Funnel traps are excellent for outdoor monitoring of the lesser grain borer. Aerial traps are sometimes deployed resting on the ground such as under shelves or packing equipment in retail and warehouse establishments. Manufacturers offer many versions of these traps with small openings that reduce excess dust accumulation, which is important because dust decreases trapping efficiency. Sticky traps can be scraped cleaned with a putty knife and redeployed multiple times following a fresh application of Tanglefoot Tangle-Trap Insect Trap Coating (Contech Enterprises, Victoria, British Columbia) or similar trapping adhesive.

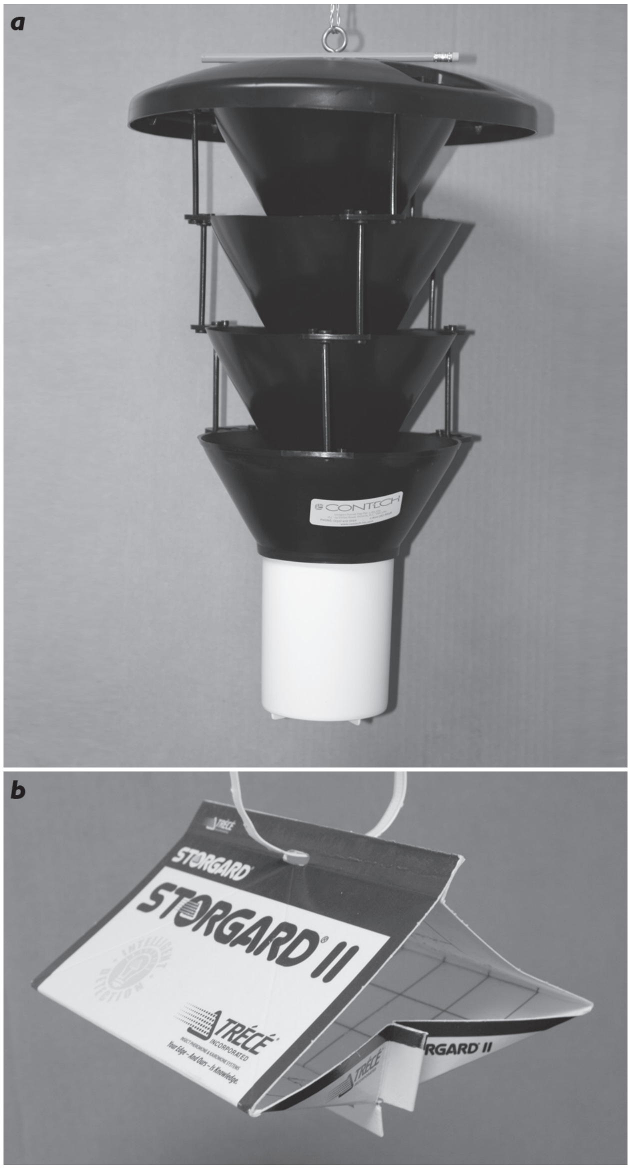

Figure 2. *Common aerial traps including a funnel trap (a) and sticky trap (b).*

Surface traps are small, low profile traps intended to rest on horizontal surfaces to capture crawling insects like stored product beetles. Surface traps will capture adults of a wide variety of insect species and occasionally wandering immatures. Surface traps are highly variable in appearance but typically constructed to take advantage of an insect's preference for seeking shelter and hiding in dark crevices (Figure 3). Traps that contain corrugated cardboard are particularly effective at attracting wandering moth larvae. Mullen (1992) developed an early pitfall trap for capturing red flour beetles with a pheromone lure. Plastic pitfall traps are molded in the shape of a cone with a hollow center where attractants can be attached and insects can accumulate; these traps usually include a cover that prevents dust accumulation.

Pitfall traps are unique in that they typically are baited with both pheromone lures and food attractants. This combination is important because some insect species are more attracted to pheromone plus food odors than either component alone. The presence of food odors may attract immatures, such as warehouse beetle larvae. Multiple studies have shown that there are many more immatures compared with adults in a stable insect population (Perez-Mendoza et al. 2004, Toews et al. 2005b). Although several species may be present in the trap, pheromone baiting tends to bias the capture frequency toward the insect for which the pheromone lure is intended.

Figure 3. *A pitfall trap, a type of specialized surface trap for capturing stored-product beetles.*

Bulk grain traps are specialized pitfall traps for use in grain stored in facilities such as concrete silos, steel bins, and flat storages. These traps are generally constructed of a perforated cylinder with a collection vial attached on the bottom (Figure 4). The principle of operation is that the trap is inserted just below the top surface of a grain mass and left in place for several days. Insects wander into the traps and fall into the collection tip where they cannot escape. Loschiavo and Atkinson (1967) first described a grain probe trap based on the idea that it would exclude grain kernels but permit entry of insects. Pheromone lures generally are not recommended for use in probe traps, although strong research in this area is lacking. White et al. (1990) provided a comprehensive review of probe trap development, construction, and factors affecting usage. Bulk grain traps are placed near the grain surface because research shows that there are more insects in this portion of the grain mass (Flinn et al. 2010). Multiple authors have addressed using probe traps to estimate population density (Cuperus et al. 1990, Reed et al. 2001, Toews et al. 2005c). An interesting advance in this area is the Insector Insect Detection System (OPI Systems, Calgary, Alberta), which includes a trap integrated with electronics to enable automated counting, insect size determination (for identification purposes), grain temperature, and a time stamp for each capture (Flinn et al. 2009). Each of these ancillary data can be helpful when interpreting insect capture data.

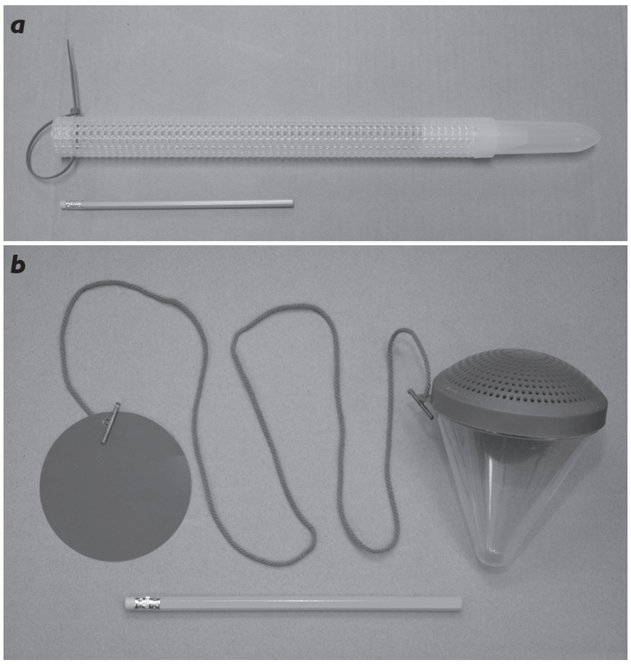

Figure 4. *Bulk grain traps including the WB probe II (a) and the PC trap (b).*

Attractants

The most common type of attractant for capturing a wide range of stored product beetles is a food odor attractant or kairomone. Commercially available formulations of food-based attractants vary from solid food attractants to a liquid blend of edible oils and stabilizers. Doud (1999) tested many different oils and found that walnut oil was a good attractant for red flour beetles. Several oils, including walnut oil, are attractive to Indianmeal moths (Nansen and Phillips 2004). Food based attractants are commonly used to capture sawtoothed grain beetles, merchant grain beetles, rice weevils, granary weevils, and rusty grain beetles. Traps designed for use with solid food attractants generally have a sticky surface inside the trap to hold the captured insects. The kairomone oil both attracts the insect and kills it by suffocation after the insect falls into the trap. Food based oils used as attractants will eventually go rancid and lose their attractant qualities with time, so it is important to change the oil every four to eight weeks. Food attractants, such as freshly kibbled grain, can also be used for monitoring species that do not have a commercially available pheromone lure. The “attractiveness” of food baits such as kibbled grain obviously depends on how much food is available in the given food facility. That is, all food baits used in traps are essentially competing with attractive odors from other food sources within the food facility.

Pheromone lures are important attractants for capture of important stored product beetle and moth adults. Lures that attract most of the common economically important species are widely available from commercial sources. Managers should be aware that pheromone lures are specific to recruiting a single species or a few closely related species. Presence of the lure will strongly bias the captures toward that species. This can be a tremendous advantage since the technician will not have to sift through hundreds of non-economically important species as would be attracted to a light source. There are exceptions to this rule. For example, commercially available pheromone lures for Indianmeal moth also attract four closely related moth species: Mediterranean flour moth, raisin moth, tobacco moth, and almond moth. The commercially available pheromone lures for red flour beetle also attract the closely related confused flour beetle. In addition, some companies market a single lure impregnated with a multi-pheromone formula. For example, they may provide a combined lure for warehouse and cigarette beetles. Pheromone components also may be impregnated into the glue in sticky traps. Although these traps have not been evaluated in controlled scientific studies, they eliminate the need to transfer lures from one trap to the next.

It is important to distinguish between sex pheromones and aggregation pheromones. Sex pheromones are very powerful attractants, but they only attract one sex (Mankin et al. 1983, Mankin and Hagstrum 1995). For example, the female Indianmeal moth produces a sex pheromone when she is ready to mate to attract conspecific male moths. Baiting a trap with the commercially produced Indianmeal moth lure will only recruit the male moths of a few closely related species. Conversely, aggregation pheromones attract both males and females to the trap. In the field, male lesser grain borers naturally produce aggregation pheromones when feeding that will attract male and female beetles to exploit the food source.

The effectiveness of combining single or multiple lures with pheromones and kairomones in the same trap is a common question. Studies show that with some beetle species, the combination of food attractant oil and pheromone is more effective than either component alone (Faustini et al. 1990). The data are much less clear about how combinations of multiple pheromones and attractant oils in the same trap influence capture efficiency (Dowdy and Mullen 1998). For example, pest management professionals commonly deploy Indianmeal moth and warehouse beetle lures in the same sticky trap; the lures need only be located in the center of the trap to maximize the opportunity for a responding insect to contact the sticky adhesive. While combining multiple species of lures in the same trap will reduce the number of traps that need to be serviced, this practice increases the probability that the trap will become saturated with insects and could require more frequent service intervals. In pitfall traps, common lure combinations include the cigarette beetle, red flour beetle, and warehouse beetle. Because the amount of pheromone in a given lure varies with manufacturer, it is important not to change lure manufacturers in the middle of a trapping program. Likewise, efforts should be made to ensure that spare lures are stored in unopened foil packages in a household freezer to prevent premature degradation.

As an alternative to pheromone lures as attractant for moths in food facilities, water by itself (Chow et al., 1977; Ryne et al., 2002; Nansen et al 2009) or water in conjunction with food and antifreeze (Ni et al., 2008) have been proposed. An important advantage of using water as attractant is that it is equally attractive to male and female moths. Water as a moth attractant does not perform well in environments where water is available. It should only be considered a possible attractant for use in stored grain silos/ warehouses and or dry food processing facilities with high ambient temperature and low relative humidity. Recommendations about shape and size of holes in water bottles are available in Nansen et al (2009). Water-baited traps for moths also may be considered as part of evaluating the performance of mating disruption programs.

Factors That Affect Trap Capture Rate

The premise of insect monitoring programs is that the number of insect captures fluctuates in response to changes in insect population density or changes in the environment. Data from many environments with numerous insect species show that this premise is valid. IPM practitioners often struggle with the idea that factors other than pest population density can affect captures. Toews et al. (2006b) showed that pheromone lure age and trap replacement interval affected captures of lesser grain borers in outdoor funnel traps. In some cases these factors can be mitigated with careful planning and routine trap maintenance. Because pest management professionals will not be able to control all of the factors, understanding their potential impact on trapping programs is critical. Professionals should study long-term trends in data sets at each facility to make educated decisions about why the number of captures changed. Unusual changes in capture rates should trigger additional investigation to identify and address problem areas.

Environmental conditions of the facility and general sanitation level around the trap will have a profound effect on the number of insects that can be trapped. For example, dust accumulation in both sticky traps and surface traps is a common problem in facilities that move or process grain. In these facilities, traps that have small openings are preferred because a smaller opening permits less dust accumulation, but stored product insects can easily find their way into the traps. Additionally, managers should conscientiously select rooms that will not rapidly become covered with dust as this could occlude dispersal of the attractants, while rendering a sticky trap surface completely useless. General sanitation level influences how far an insect must travel to meet its biological needs. Ecologically speaking, warehouses are temporally and spatially fragmented landscapes; the degree of spatial fragmentation determines how far the insect will need to travel to find food, shelter, and mates. Increased travel distance is correlated with increased potential for encountering a trap. For example, Roesli et al. (2003) showed that the number of weevils captured in pitfall traps located in pet specialty stores increased by more than 50% immediately after vacuuming, sweeping spilled food, and removal of severely infested products. Nansen et al. (2004e) showed that surface trap captures of beetles in pet stores increased immediately after sanitation but resumed to lower levels after a few weeks. In these cases the increase in trap captures was interpreted as beetle populations being "disturbed" rather than actually controlled by the sanitation procedures.

Trap position will affect capture rate. Research shows that traps positioned under refugia, in corners, along walls, and near food sources capture more insects. Managers should consider the condition of concrete floors and walls in warehouses when interpreting captures. Old floors that are cracked and have product accumulation in the cracks will harbor insect populations that would have to range over much larger areas if the surface was clean and contiguous. Similarly, cracks near the junction between the floor and wall will permit insects to infest wall voids. They provide a conduit to wall voids and to the ceiling, where flour accumulates and is difficult to clean.

Indoor conditions such as air temperature, air movement, light, and photoperiod (light and dark cycles) affect insect captures in traps. Biology students learn that arthropods are poikilothermic; that is, their body temperature and metabolism rate are governed by the ambient temperature. A mobile insect, such as a red flour beetle adult, is more active and likely to be captured when the inside air temperatures are between 90˚F and 100˚F (32˚C to 38˚C) compared with an inside temperature in the 65˚F to 75˚F range (18˚C to 24˚C). Toews and Phillips (2002) investigated capture of rusty grain beetles in stored wheat and observed a quadratic increase in captures between 20˚C and 40˚C. Regardless of species, few insects will be captured indoors or outdoors when the air temperature is less than 60˚F (15.5˚C). Air currents carry pheromone plumes and food odors to areas where insects are likely to detect these chemical cues. Hence, traps are visited by more insects if positioned near doors and windows, in rooms with air handling units, or near moving machinery. Light and photoperiod can be especially important when sampling moth populations as they tend to have the highest flight activity immediately after the lights are turned off.

The intrinsic mobility of a given insect species will determine how often they are captured in traps. For example, stored grain pests like rice weevils and lesser grain borers move very little in grain bulks compared to rusty grain beetles. For this reason, the presence of a single weevil or lesser grain beetle in a probe trap may be cause for concern, but the capture of several thousand rusty grain beetles can be tolerated until the grain is sold. In warehouse and retail environments, strong fliers like the Indianmeal moth and warehouse beetle will be detected much farther from the food source compared to insects like the red flour beetle or merchant grain beetle. This can be exploited by the pest management professional, because capture of more than one or two merchant grain beetles in the same trap strongly suggests that the source of the infestation is in proximity of the trap.

Pest management professionals may utilize concurrent application of residual insecticides and insect monitoring using traps. Ironically, recent research showed that the use of residual insecticides (for example: Conquer, Suspend SC, Talstar P, or Tempo SC Ultra) resulted in fewer red flour beetles being captured in traps and measurable increases in dead adults observed on the floor, but no change in the population density of the flour beetles in the food patches (Toews et al. 2009). These observations strongly suggest that managers relying on trap captures in insecticide treated structures could easily be deceived into believing that the insecticide was suppressing insect population growth when, in fact, the population was constant or even increasing. Dead insects on the floor should be considered a useful indicator of a continuing infestation rather than evidence that the insecticide program is successful.

Developing and Managing a Trapping Program

Books and other extension publications provide specific recommendations for operating a trapping program. Research and practical experience strongly suggest that grain storage, food processing, warehousing, and retail facilities are far too diverse to expect a single set of recommendations to be adequate. The purpose of this section is to help practitioners address six fundamental questions when developing a trapping program:

- What type of trap should be used?
- Should pheromone lures and oil attractants be utilized?
- How many traps are necessary?
- Where should traps be located?
- How often should traps be serviced and lures replaced?

- Is every insect species captured economically important?

In addressing these questions, pest management professionals should realize that some level of experimentation will occur in operating a trap-based sampling program. Many of the following examples are based on studies of the Indianmeal moth in food processing facilities, but the case studies are relevant for other moth pests such as almond moth, raisin moth, and Mediterranean flour moth. Similarly, studies with red flour beetle, warehouse beetle, rusty grain beetle, and the lesser grain borer are highlighted below, and those examples are similar to other beetle pests.

What type of trap should be used?

The answer requires careful assessment of the pest community in the given food facility and an attempt to identify the most economically important species that will be targeted. Information about the most likely pests for a given combination of food products and geographical region can be readily obtained through university Extension programming, reputable pest control operators, distributors of trapping devices, and industry peers. After establishing which pests to target, the next step is to evaluate available traps. Traps vary in price, size, durability, placement restrictions, and potential for using different attractants, such as food attractants or pheromone lures. Research comparing insect captures among traps is available. For example, Campbell et al. (2002a) conducted an experiment to compare warehouse beetle captures in hanging Pherocon II sticky traps with FLITe-TRAK pitfall traps placed on the floor immediately below the aerial trap. The two types of traps were placed in the same horizontal distribution pattern with 37 traps of each trap. Trapping was conducted for nine consecutive weeks. Because of their placement on the ground, almost one-third of the FLITe-TRAK traps were lost because of warehouse operating procedures. Mean captures in the FLITe-TRAK traps were almost twice of those with Pherocon II traps. In other words, either the trap itself or the vertical placement greatly influenced captures of warehouse beetles. The number of "zero captures" (empty traps) was 96 with Pherocon II traps, but only 30 with FLITe-TRAK traps. This example illustrates that trapping of the warehouse beetle appears to be most effective when traps are placed on the ground; however, traps on the ground are more vulnerable to getting lost or damaged.

As part of the selection process, carefully review the existing literature and consult with vendors of insect trapping supplies or extension services to reduce the list to the two to three most likely trap candidates. One recommendation is to purchase a few traps and conduct in a simple comparative study in two to three separate rooms or portions of a food facility. Consider a situation where you have identified three potential traps: T1, T2, and T3. Next, identify a stored product facility with three distinct trapping spaces (rooms or floors) with insect infestation: R1, R2, and R3. Conduct weekly trapping for nine consecutive weeks following a pattern with weekly rotation of traps (Table 1).

Table 1. *Suggested trap rotation among three rooms and example insect captures to evaluate how performance of three trap types can be assessed during nine weeks of trapping.*

	Room in Facility			Example Number of Captures		
Week	Room 1 (R1)	Room 2 (R2)	Room 3 (R3)	Room 1 (R1)	Room 2 (R2)	Room 3 (R3)
1	T1	T2	T3	6	3	0
2	T3	T1	T2	3	6	0
3	T2	T3	T1	4	3	2
4	T1	T2	T3	5	2	1
5	T3	T1	T2	4	7	2
6	T2	T3	T1	4	4	1
7	T1	T2	T3	2	3	2
8	T3	T1	T2	3	4	2
9	T2	T3	T1	3	3	2
			Total	34	35	12

By operating all three traps in all three rooms in different weekly intervals, it is possible after nine weeks to rank the captures with each trap and see if one trap candidate is consistently trapping more insects than the other trap candidates. For example, hypothetical trap captures are shown in Table 1. From the last three columns note that weekly captures varied and captures were higher in rooms 1 and 2 compared to room 3. Despite the variation, note that trap 1 caught 13 of the 34 insects trapped in room 1, 17 of 35 in room 2, and 5 of 12 in room 3. Thus, it caught considerably more than 33% of the trap captures and therefore seemed to perform better than the other two traps. A similar comparative approach can be used to examine different placement options of traps and for comparison of trap lures. Other important considerations regarding choice of trap type include proportion of traps lost, how easy the traps are to service, and whether trap captures tend to show trends over time or indicate meaningful spatial distribution patterns (see section on trap data interpretation).

Should pheromone lures and oil attractants be utilized?

The purpose of using an attractant (pheromone lures and oil attractants) is to increase the capture rate. Apart from probe traps inserted into unprocessed food products, unbaited traps typically capture very few insects. There are few studies showing that trap color, color contracts, and trap shape are important for effective trapping of stored product moths (Levinson and Hoppe. 1983, Nansen et al 2004d). Most stored grain insects show highest level of flight active around dusk and dawn, so they respond much less to bright colored traps (like yellow traps placed in gardens) than, for instance, flies, mosquitoes, gnats. Pheromone lures and food-based oils are the most important attractants used in traps for monitoring of stored grain insects. The question of which lure or attractant to use can be studied based on a simple comparison of lures (as outlined in the study of trap types in Table 1).

A couple of important additional concerns regarding effective use of trap lures need to be addressed. Suppose a highly attractive lure was available that attracted insect individuals within a range of 50 to 100 m of the trapping station. Such a lure will obviously enable high insect captures, but how should those captures be interpreted if insects were attracted over such long distances? It seems reasonable to argue that a lure with much shorter trap catch range (distance or range of attractiveness) may be more appropriate for meaningful interpretation, especially if the objective is to interpret the spatial distribution pattern of insect pests and to locate "hot spots" with high pest incidence. Mark and recapture studies with Indianmeal moths have demonstrated that these moths migrate among floors in flour mills and can migrate as far as 137 m within food processing facilities (Campbell et al. 2002a). Nansen et al. (2006b) released groups of 30 Indianmeal moth males from a single known location in an otherwise empty space with 30 pheromone-baited trapping stations arranged in a 3 m by 3 m grid. With the release point (supposedly the position of high insect densities) known, the question was how well pheromone-based trap captures could identify that area. Figure 5 below shows results from three of the male moth releases; the release point is indicated with a cross and increasing magnitude of captures is depicted by increasing bubble diameter. Interestingly, the results from that study suggested only a modest correlation between trap captures and distance from release point. In other words, it was not possible to accurately pinpoint the release point (or theoretical infestation) based on trap captures.

An important characteristic of trap lures is that they may be more attractive to a specific proportion of the insect pest population, which means that the trap captures may not be representative of the entire insect pest population. For instance, sex pheromone lures for trapping of moths are only attractive to males. Several careful experimental studies have shown that age and mating status of the individuals caught in traps may not be representative of the pest population at large. Also, the life stages captured may not be the ones actually damaging food products. This is clearly the case with stored product moths; adults are exclusively captured in the traps but the damage is caused by larvae.

How many traps are necessary?

This question is important for several reasons: more traps increase costs and labor needed to maintain the trapping program, so it is important not to deploy more trapping stations than necessary; stored product insects may vary greatly in response to commercial attractants; and stored food products vary in value depending on processing level and overall

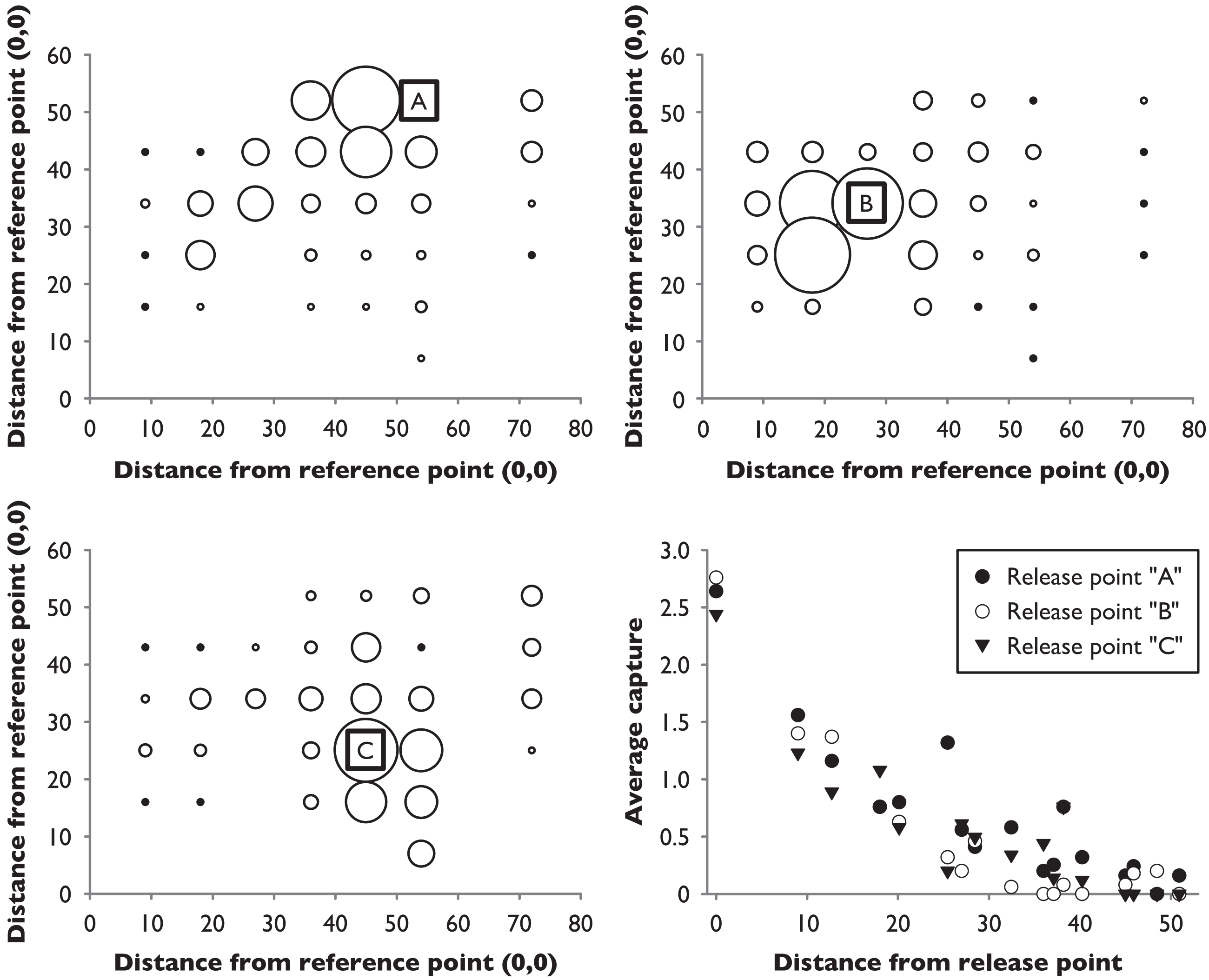

Figure 5. *Bubble plot of moth captures in relation to the release point of the moths in an empty warehouse. X's mark the release point while circles with proportionately larger diameters indicate increasingly larger numbers of captured insects at that location.*

market price (crop seeds are much more valuable than regular unprocessed grain). Typically, there is a positive correlation between food product value and number of trapping stations deployed. The choice of how many trapping stations to deploy depends on the overall objective of the trapping program. If the main purpose is to monitor changes in insect trap captures over time, then continuous service of 10 to 20 stations may be sufficient for a given facility. Considerations such as facility size, number of floors, complexity of trapping environment, and varying temperature conditions are all good reasons to increase the number of traps.

One way to evaluate the number of trapping stations necessary is to select a high number of trapping stations initially and reduce the number of traps deployed during consecutive weeks. Set the largest number of traps deployed equal to 100% and then conduct trapping with random sequences of trap numbers representing 50% to 90% of that total during subsequent weeks. Based on weekly captures, calculate the average number of insects per trap and determine at what trap density captures appear to stabilize. For instance, imagine that the following captures are obtained during a 12-week experimental trapping period (Figure 6). The theoretical example illustrated in Figure 6 shows that average captures varied greatly when 10 to 12 trapping stations were used, while they were much more consistent when more than 20 trapping stations were used. This simple exclusion study can be used to determine the appropriate number of trapping stations in a given stored product facility, but the complexity of the facility is important in deciding how many traps to deploy (Campbell et al. 2002a).

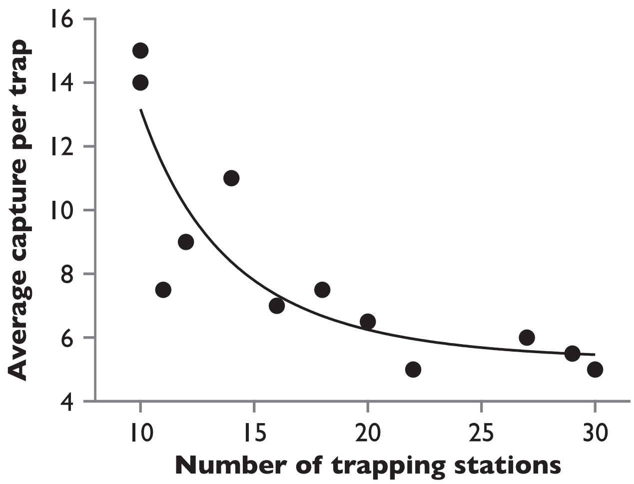

Figure 6. *Relationship between number of trapping stations and average moth captures.*

Where should traps be located?

One of the key aspects of trap placement is to know the "attractive range," or from how far target insects will be attracted. There are no detailed scientific studies addressing how far apart pheromone baited traps should be placed under commercial conditions, and there are so many variables that it may not be feasible to address this issue. The only scientific evidence, conducted under experimental still air conditions, suggests that sex pheromone lures are attractive to moths at distances of about 4 m (Mankin et al. 1999). This should be considered the minimum trap distance when commercial lures are used. No controlled studies were found in the literature on trap catch range with food-oil based lures.

Most researchers place trapping stations 20 to 50 m apart in food processing facilities. In large facilities, this distance is highly influenced by costs and positioning of pillars or similar structures that are convenient for trap placement. Ventilation systems, open doors, and machinery producing heat and air currents will affect the shape and size of attractive plumes being emitted from the trap. A lure may have a much wider trap catch range if a ventilation fan generates an air current that passes through the trap and increases pheromone dispersal. One must also consider that the concentration of attractant in the plume decreases with distance from the lure. Insects attracted to a pheromone-baited trap move upwind towards higher pheromone concentration, so the size, shape, and consistency (level of turbulence) of a pheromone plume can greatly influence the likelihood of an insect being able to locate and be captured in a given trap. Constant changes in air currents occur inside food processing facilities because of moving objects and ventilation systems. A practitioner of insect trapping must realize that the complex nature of the stored product facility can influence trap captures.

Another aspect of trap placement is vertical positioning. Food processing facilities and warehouses are comprised of large buildings with multiple floors and rooms sometimes reaching 5 to 10 m in height. The question of how high aerial traps should be positioned off the ground has received little attention. In one of the few studies specifically addressing this aspect of trapping programs, Nansen et al. (2004d) used freely suspended pheromone baited Pherocon II aerial traps on a vertical string at different heights above the floor (Figure 7). When traps were away from the walls, more moths were captured closer to the floor and near the ceiling. Captures were similar at all heights when a landing platform was added or the traps were placed near a wall (Figure 7).

Several important conclusions can be drawn from this study and studies of pyralid moth mating behavior. Phelan and Baker (1990) provided drawings of pyralid moth courtship behavior and demonstrated how males fly toward the calling females but walk the last part of the way before encountering the female. It appears that male moths responding to the synthetic pheromone are more likely to enter the Pherocon II trap when there is an adjacent surface (floor, ceiling, or landing platform). In commercial settings, diamond-shaped pheromone baited traps are often suspended freely from pipes or other structures. Data presented here clearly demonstrate that traps may perform quite differently simply because of their vertical position and/or proximity to surfaces. Trap capture efficiency may be increased by placing traps on the floor. Similar results were obtained in a trapping study of the warehouse beetle (Campbell et al. 2002a). Unfortunately, traps placed on the floor are also more likely to be lost or damaged so careful marking and consideration of trap site is critical.

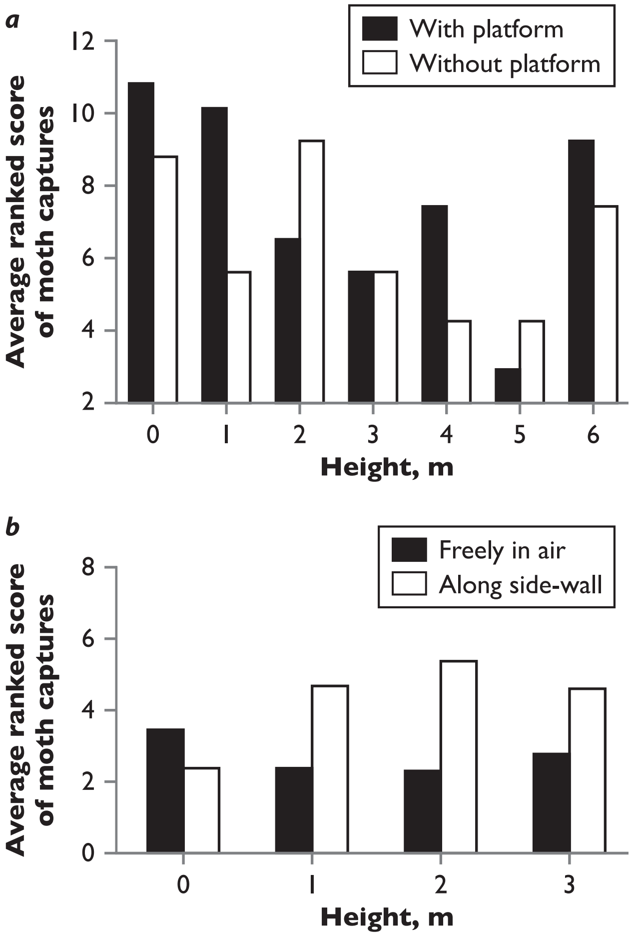

Figure 7. *Trap captures of moths along vertical gradients with/without a platform attached the pheromone baited sticky trap (a) and (b), or when traps are placed freely suspended or alongside wall (c).*

How often should traps be serviced and the lures replaced?

The service interval, defined as the amount of time between checking traps, is important. Stored grain insects complete their life cycle within 21 to 35 days, so a monthly service interval means that only one data point is obtained per generation. Risks of monthly service include changes in food availability (turnover of food products); changes in weather patterns and insect mobility, including flight; and environmental changes due to sanitation or other operational procedures. Each of these factors can cause marked changes in insect mobility and therefore increases in trap captures even though pest populations are unchanged. Monthly trap service will increase the risk of substantial insect damage before a problem is detected. Generally speaking, traps should be serviced on a 7- or 14-day schedule. Make sure trapping stations are serviced the same day and that all lures are replaced to enable direct comparisons of captures among traps. The question about how often to replace lures depends on the lure. Some synthetic sex pheromones for stored product moths remain attractive for many months, while the aggregation pheromone for lesser grain borers loses attractiveness in one week. Generally, lures for red flour beetle, warehouse beetle, and Indianmeal moths should be changed every four to six weeks.

Is every insect species captured economically important?

Species composition of the captured insects is also critically important. In bulk grain storage, there is seldom an economic incentive to fumigate in response to the presence of external infesting insect species, even at relatively high population densities. Examples of commonly encountered external infesting species in bulk grain bins include the Indianmeal moth, sawtoothed grain beetle, red flour beetle, hairy fungus beetle, flat grain beetle, and rusty grain beetle. Conversely, internal infesting species such as Angoumois grain moth, rice weevil, granary weevil, maize weevil, lesser grain borer, bean weevils, and khapra beetle are serious and economically important pests of stored commodities. The khapra beetle is arguably the most serious pest of stored products worldwide and is under strict quarantine from the United States. Population development by internal infesting species should initiate conversations about the intended use of the raw commodity, how much longer the commodity will be stored, ability to manage temperature and moisture content, and potential for effective fumigation.

Insect species composition is an equally important consideration in the food processing, warehousing, and retail segments of industry. Because consumers will not tolerate visibly contaminated foodstuffs, the same externally infesting stored product insect species that are not an economic problem in bulk stored grain are indeed a problem in this arena. Additional species of common economic concern include the warehouse beetle, cigarette beetle, drugstore beetle, merchant grain beetle, Mediterranean flour moth, rice moth, and almond moth. Facilities that utilize animal proteins may develop infestations of larder beetles and red legged ham beetles. These animal feed products become particularly susceptible to infestations if the feed products become moist, which may happen if machinery is creating steam or roofs or walls are leaking water. Managers need to realize that not all insect species captured in traps infest grain or processed foods. Research shows that general predators and fungus feeders persist in many structures. Ground beetles, fungus beetles, click beetles, and antlike flower beetles are all large families of beetles that fit this category and have been captured in stored product insect traps.

Data Interpretation

It is important to understand that there are considerable differences in the number of traps required for various purposes. Characterization of seasonal changes in pest population dynamics over time can be conducted successfully with 10 to 20 trapping stations. Long-term trapping data are valuable for interpreting the impact of changes in operating procedures, fumigations, or other management tactics. They can also show how seasonal differences affect pest populations. Conversely, spatial analyses such as contour mapping and use of spatial statistics generally require more data points. In fact, some authors provide empirical data suggesting that insect counts from traps may not be the best candidates for predictive spatial pattern analyses (Nansen et al. 2003, 2006a).

Environmental effects on trap capture interpretation

A given set of trapping data is highly dependent on the environmental conditions in the sampling universe (the trapping space). For example, a capture of 10 moths is not necessarily twice as concerning as capturing five moths, because so many interacting factors can be responsible for an increase in trap captures. Toews et al. (2005a) trapped red flour beetles in experimental arenas with different levels of environmental heterogeneity and complexity. Under experimental conditions, they showed that beetles were predominantly captured in the corners of the room and underneath structure like shelves. They also showed that there was a stronger correlation between known insect density and number of insect captures when food was absent, which means that sanitation practices can greatly impact trapping captures. In a study of beetle captures in commercial pet stores, Nansen et al. (2004e) showed that captures of several beetle species increased markedly immediately after implementation of sanitation practices but later resumed to pre-sanitation levels. Similarly, changes or fluctuations in ambient temperatures, light conditions (Bell 1981), and movement of food products can greatly impact trap captures. The presence of food material in the environment around a trap can influence insect captures in traps and this is likely to vary over time and among trap locations. A lack of food due to increased sanitation will cause insects to search larger areas, which will increase trap captures (Nansen et al. 2004e). Managers should also collect environmental data including temperature, humidity, and information about sanitation procedures, movement and turnover of food products. This information can be of critical importance when trying to interpret trapping data in both spatial and seasonal contexts.

What does the number of caught insects actually mean?

There are many studies suggesting that there is not always a tight correlation between captures of stored product insects and insect population densities (Vela-Coiffier et al. 1997, Hagstrum et al. 1998, Campbell et al. 2002a, Nansen et al. 2004c, Toews et al. 2005b, 2005c, 2009). As a possible solution to this problem, Nansen et al. (2008) proposed a binomial approach to trap capture interpretation, in which they focused on the proportion of empty traps. Instead of counting how many insects were captured or examining average counts per trap, they based their interpretation on how many traps did not capture any insects. Two major advantages to this approach are that it is much easier and faster to determine the proportion of empty traps than to count how many insects were caught in each trap; and working with proportional data (empty traps / total number of traps) eliminates data outliers. Nansen et al. (2008) showed that a wide range of data sets followed a similar frequency distribution. A baseline trapping data set may suggest that action against a given insect pest should be taken when the proportion of empty traps falls below 0.40 or 0.20.

Toews et al. (2006a) approached the problem of trap capture interpretation by focusing on both the quantity and distribution of captures in space. The researchers suggested concurrent plotting, by species, of the proportion of traps with at least one capture, overlaid with the capture mean and standard error of only the traps containing captures (Figure 8). Using this method, a consultant can easily assess an increasing insect population by the presence of

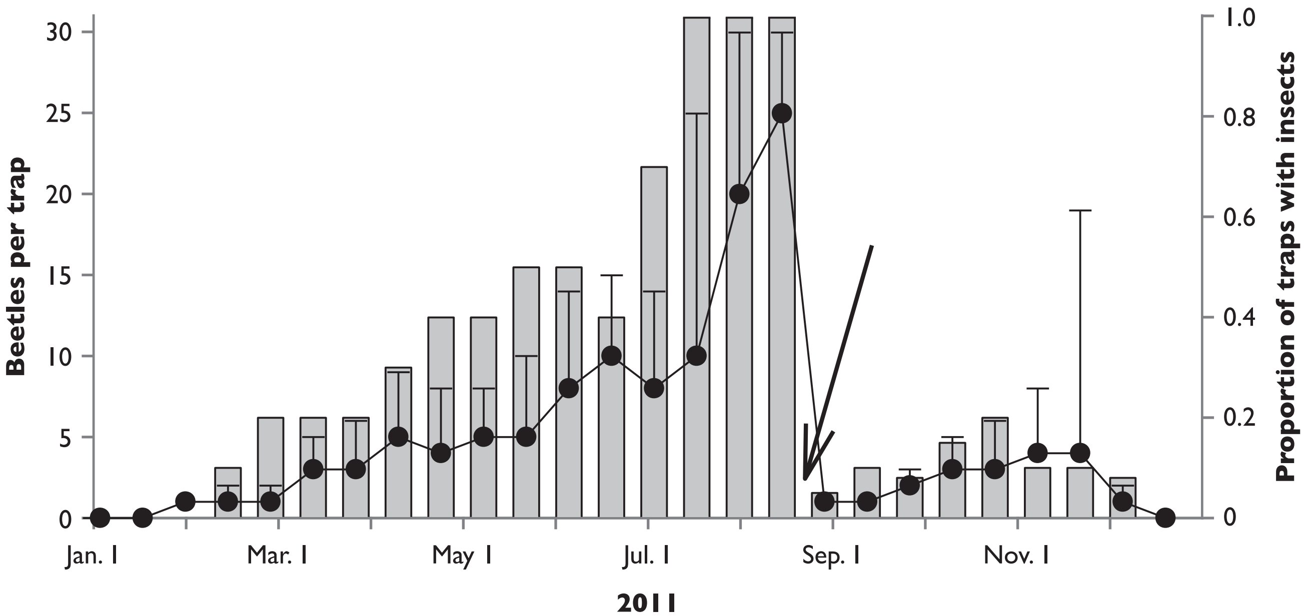

Figure 8. *Illustration of red flour beetle captures in pitfall traps. Vertical bars (right axis) indicate proportion of traps containing at least one insect, means and standard errors (left axis) represent captures in traps containing at least one insect (no zeros included in mean and standard error calculations). The arrow shows when a fumigation was conducted.*

an increasing proportion of traps, with at least one capture (January 1 to August 15 on Figure 8). Little change in the proportion of traps with at least one insect coupled with a disproportionate increase in the standard error (or no standard error) (November 20 on Figure 8), indicates a localized problem that should be handled with direct interventions. Examples could include improved exclusion, screen repairs, repair of door sweeps, improved sanitation, or targeted application of residual insecticides. The absence of an increasing proportion of traps with at least one capture coupled with a significant increase in the mean number of captures with a proportionate increased standard error would indicate that the population is increasing in a relatively small area. Obviously, both increasing means and proportion of traps with captures indicates a more serious problem; depending on the situation and time of year this could be used to justify a global intervention such as fumigation.

Advanced spatial interpretation

Spatial analyses are used to characterize the relationships among sample data points and then interpolate values between points. Spatial mapping of insect counts has been used to show changes in stored product insect density in grain storage (Arbogast et al. 1998), in food processing plants (Campbell et al. 2002a), and in outdoor habitats (Nansen et al. 2002). This type of analysis is typically used to identify specific areas for enhanced control or suppression efforts. In contrast to conventional statistical approaches that assume each sample point is completely independent, the general premise of spatial analysis is that sample points that are closer together are more correlated than sample points that are farther apart. The usefulness of these maps is directly proportional to the number of sample points used to construct them. In other words, the tradeoff to using fewer traps is less precise predictability. There are many methods used to interpolate the areas between the sample points, each with important theoretical and statistical considerations that are beyond the scope of this publication. While those algorithms and computations are complex, the process of simply generating a contour map using a software program is relatively easy. Each trap location in the data set must be associated with x and y coordinates that accurately represent the location of that particular trap in space. In a spreadsheet, simply list x-coordinate, y-coordinate, and number of captures in three successive columns, and then import those data into a software program such as Surfer 10 (Golden Software, Golden, CO). Brenner et al. (1998) provide suitable background information for creating spatial maps for spatially targeting insects in structures.

Another approach to spatial interpretation is to use simple "bubble plots." The investigator creates scaled maps in which increasing bubble diameters indicated trap locations where larger numbers of insects were captured. Nansen et al. (2009) used this technique to interpret moth captures in specially designed water bottles that were suspended in a 3 m by 3 m grid in commercial peanut warehouses. This study showed gradual increases in moth populations over four weeks, but weekly patterns of trap captures indicated clearly distinct zones either with or without moth captures (Figure 9). Thus, even though trapping stations were only a few meters apart, it was possible to detect zones with hot spots and zones without moths.

Impact of outside conditions

The importance of pest immigration into grain and food processing facilities is readily apparent in long-term data sets (Toews et al. 2006a, Campbell et al. 2010a, 2010b). Monitoring outdoor pest insect populations can often explain why indoor pest populations change (Campbell and Arbogast 2004). This is true because stored product insects are well adapted to survival and reproduction in a variety of natural and manmade habitats. Newly emerged adults will find and exploit patchy habitats, and it is extremely difficult to completely exclude insect pests from stored product facilities. Studies of the lesser grain borer and its close relative, the larger grain borer, revealed that these pests are abundant in

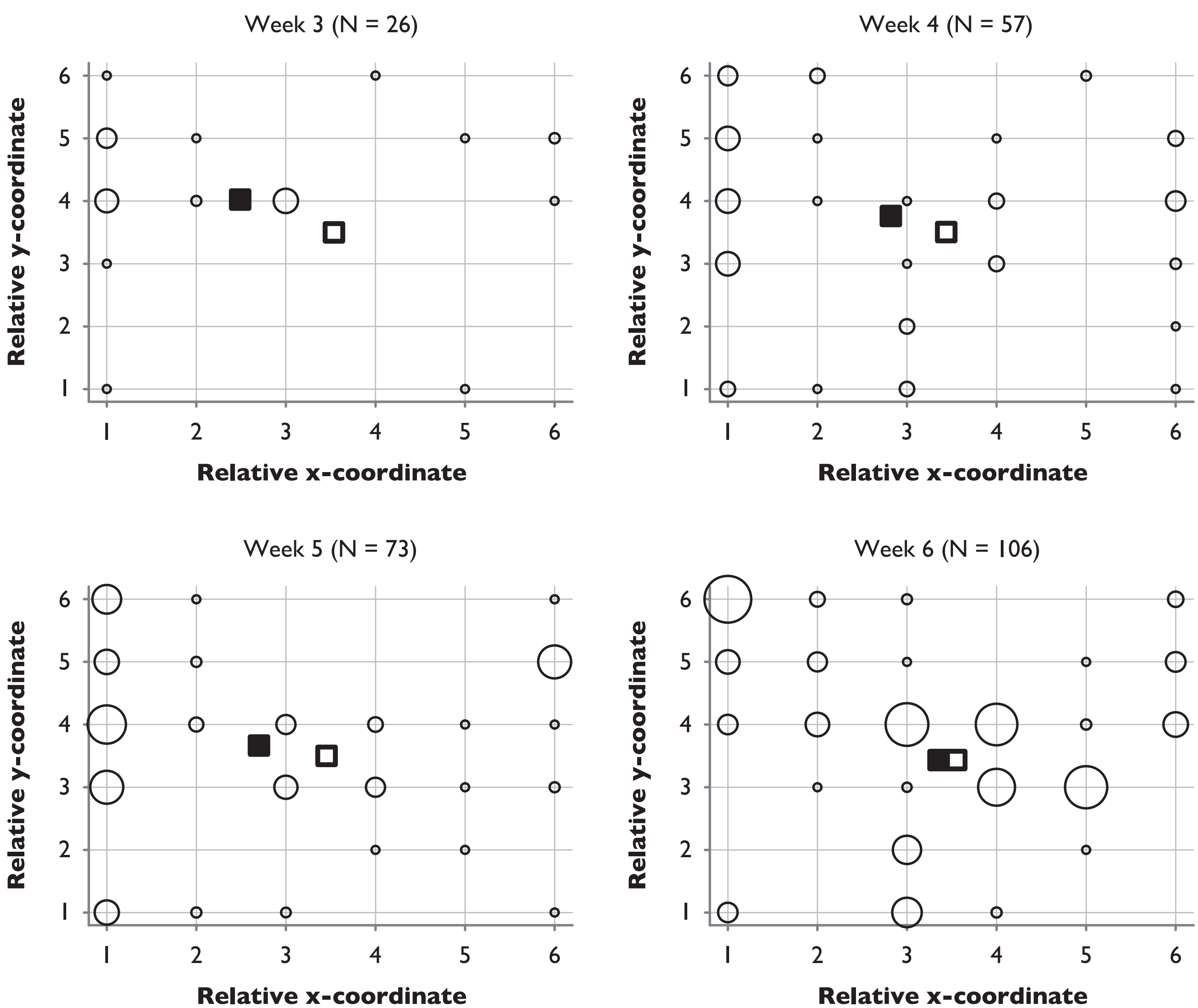

Figure 9. *Bubble plots of insect captures by week in a commercial peanut plant with size of circles depicting the magnitude of captures. Total weekly captures varied between 26 and 106 moths. Empty squares represent the sampling centroid and filled squares trap capture centroids.*

natural habitats and are able to complete their life cycle on tree nuts (Nansen et al. 2004c; Edde et al. 2005; Edde and Phillips 2006, Jia et al. 2008). Toews et al. (2006b) compared lesser grain borer captures in outdoor traps and traps suspended from the ceiling inside a modern bagged grain storage facility; those data showed highly significant correlations between these locations. Campbell and Mullen (2004) captured warehouse beetles and Indianmeal moths inside and outside food processing and storage facilities. There seemed to be considerable movement of stored product insects both migrating out of and immigrating into stored product facilities. Finally, Toews et al. (2006b) monitored stored product insect pests on unbaited rodent glue boards placed around overhead doors and documented seven species with distinct seasonal population trends. These compelling data showcase how indoor captures can be predicted with outdoor captures. They could also be used to explain why indoor insect captures continue immediately after fumigation (Campbell and Arbogast 2004, Toews et al. 2006a, Campbell et al. 2010b).

The potential value of outside trapping is further supported by a considerable body of research demonstrating that weather variables can be used to characterize seasonal fluctuations in stored grain insect captures (Nansen et al. 2001; 2004a; Edde et al. 2006; Toews et al. 2006b). Changes in insect captures can be attributed to a wide range of circumstances (change in temperature, barometric pressure, humidity, food availability, and disturbance) without actually representing a change in pest population density. Concurrent logging of temperature and relative humidity can help with interpretation. Campbell et al. (2010b) showed that there was a direct relationship between indoor temperature in an operating mill and outdoor temperature. The trap data management spreadsheet or digital storage system should allow the practitioner to enter climate data and data concerning food availability, sanitation, operating machinery, insecticide applications (including fumigations), heat treatments, and other control tactics (Roesli et al. 2003).

It seems reasonable to propose that practitioners of trapping in commercial stored product facilities and applied researchers collaborate on development of weather based risk warning systems, which could serve to alert food facility managers about when high levels of insect flight activity (and therefore risk of infestation) should be expected. Such weather-based risk warning systems would involve careful analysis of how weather variables affect insect flight activity (Nansen et al. 2004b). In Figure 10, the bold line represents a seasonal baseline, which may have been developed on the basis of how weather variables influence insect flight activity, and it may require several years of initial trapping before such a seasonal baseline can be developed. The seasonal baseline clearly indicates that the given insect has higher flight activity in the summer months than during other parts of the year. The dots represent trap captures obtained after the seasonal baseline was developed, and the idea behind this interpretation approach is that trap captures should be of concern if they exceed those depicted by the baseline with a certain margin. In other words, a trap capture of five moths in July would not be considered alarming, because that is during the time with high level of flight activity. Conversely, five moths per trap would be alarming from December through February.

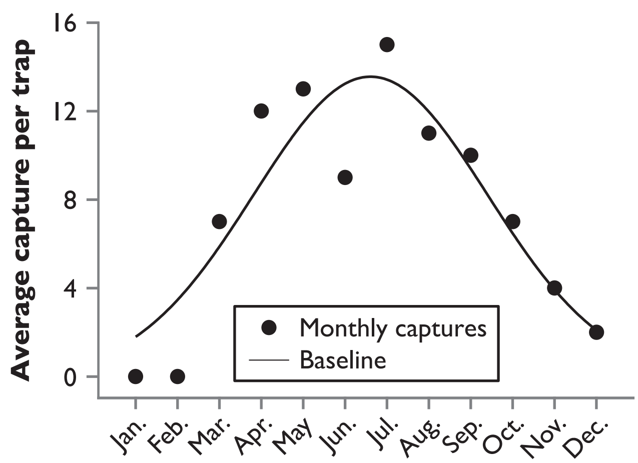

Figure 10. *Illustration of how a trapping baseline can be used to interpret seasonal trap captures.*

Conclusion

The use of traps and subsequent interpretation of insect captures for monitoring and population estimation are the most efficient and cost effective tools available. Practical, economic, and ecological considerations require pest management professionals to conduct some level of experimentation each time a new trapping program is initiated. Data generated using traps and interpretation provides the best pest management decision support.

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