Transmission Threshold

The level of abundance of a parasite, or the abundance of its vector, that is necessary for disease to spread.

Transovarial Transmission

Passage of a material through the ovariole and within the egg.

Transovum Transmission

Passage of a material on the surface of the egg.

Transpiration

The evaporation of water from the surface of plant foliage.

Transposable Element

An element that can move from one site to another in the genome. Transposable elements have been divided into two classes, those that transpose with an RNA intermediate, and those that transpose as DNA.

Transposon

A transposable element carrying several genes including at least one coding for a transposase enzyme. Many elements are flanked by inverted repeats. *Drosophila melanogaster* contains multiple copies of 50–100 different kinds of transposons.

Transstadial Transmission

The transmission of pathogens or parasites through successive stages of the host's life cycle, as from the egg to the larva, pupa and adult.

Trap Crop

A crop or portion of a crop that is intended to lure insects away from the main crop.

► Cover, Border and Trap Crops for Insect and Disease Management

Traps for Capturing Insects

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Traps developed for capturing insects are as varied as the purpose for the trapping, the insects targeted, and the habitats in which they are used. Traps are used for general survey of insect diversity, and these usually are simple interception devices that capture insects moving through an area. Traps also are used for detection of new invasions of insect pests in time and/or space, for delimitation of area of infestation, and for monitoring population levels of established pests. This information is used to make decisions on the initiation of control measures or to measure effectiveness of a pest management program. Traps may be used as direct control measures, for example, by mass trapping (use of a high density of traps throughout the infested area) or by perimeter trapping (use of traps as a barrier around a pest-free area to intercept insects moving into the area) to remove a large number of individuals, with the goal of preventing or suppressing population buildup. Traps can be used as direct control measures if they are highly effective, if they capture a high percentage of females (especially if they capture them before they have a chance to lay eggs), and if they are integrated with other pest management approaches. Factors such as cost per trap, the need to service the traps frequently and the high reproductive rate of individuals that escape capture, however, prevent widespread use of traps as a stand-alone pest control measure (Figs. 97 and 98).

Traps for specific insect species or pest groups may use combinations of cues to lure the target insect and exploit aspects of the insect's behavior to facilitate movement of insects into the trap. Several factors influence the effectiveness of a specific trap. The ability of the trap to mimic and present those cues to the insect, the strength of those cues in influencing the insect's behavior, and the proper placement of the trap in the habitat are important.

Following is an overview of the basic trap types, and variations of those basic trap types for specific uses. Traps may be used with or without attractant cues, and may use a combination of cues, including visual (color, light, shape), chemical (food/host, pheromone, parapheromone, oviposition) and acoustic stimuli to make them more specific and/or more effective. Automated monitoring systems exist that will transmit information on trap capture to an offsite station. Insect traps are an important part of insect pest management programs. Although a number of trapping systems are discussed, the intent is to provide a general framework of types of traps that are used with some representative examples. It is not intended to be a complete listing of all traps that have been developed or are in use. Representative literature is presented at the end of the section that will provide additional information on insect traps and specific uses.

Trap Types

There are a few basic designs that describe almost all insect traps. They may be a surface that is presented flat or is formed into baffles or cylinders; containers with holes on the sides, top or bottom; and funnels leading up or placed over the container to hold captured insects. However, different types of traps are used for insects moving through air (that is, flying or wind-borne insects), ground-dwelling or walking insects, subterranean insects, or aquatic insects. A number of these are described below.

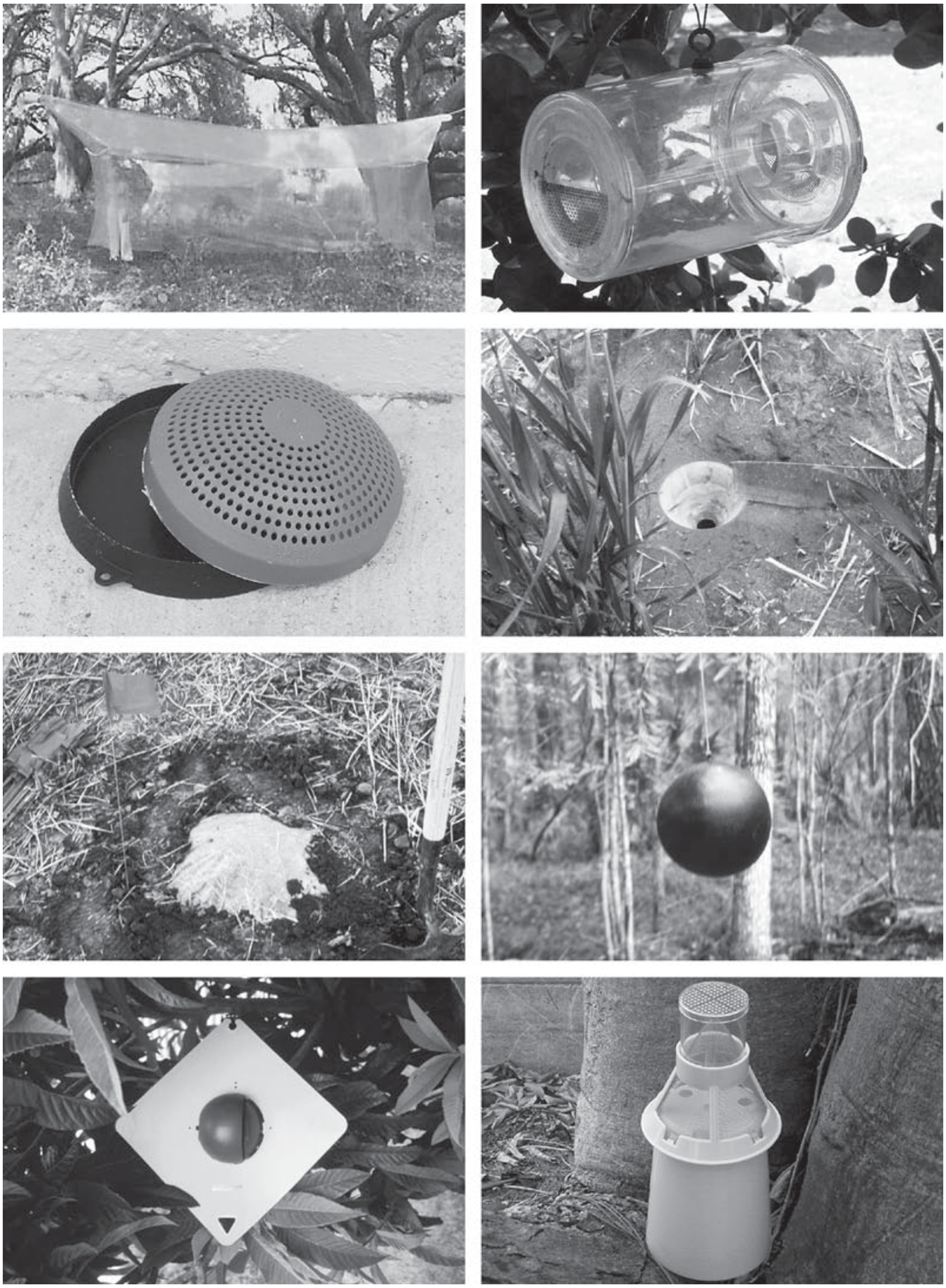
Traps for Flying Insects and Wind-Blown Insects

Interception Traps

Interception traps are commonly used for faunal surveys in ecological studies, although they can also have pest management applications. In its simplest form, it is a suspended net with an invagination along the top that leads to a collecting tube. The Malaise trap is an example of an interception trap. Fixed interception traps have been used to study insect migration, with separate collecting tubes for north-bound versus south-bound insects. Or, the trap may be used with a wind vane attachment so that the flat surface of the net swivels to face into the wind. Large, funnel-shaped nets have been mounted on moving trucks for sampling flying insects such as biting midges (Ceratopogonidae) or attached to a suction device to sample Russian wheat aphids, *Diuraphis noxia* (Mordvilko).

Sticky Traps

Panels, cylinders or spheres covered with sticky material are probably the most commonly used traps for faunal surveys in agricultural studies. In the simplest form, they may be clear panels that are coated with a material that will retain insects that are blown onto the panel or fly into it. Panels may also be used with a color and/or a shape and a chemical attractant. Very small insects will be retained by a thin coating of motor oil, but larger insects may escape this substance. To capture both small and



Traps for Capturing Insects, Figure 97 **Some insect traps: *top left*, Malaise trap, an interception trap for capture of flying insects; *top right*, Steiner trap, a lure-based trap used for capturing fruit flies; *second row left*, PC floor trap, a lure-based trap for stored product insects; *second row right*, pitfall trap for capture of insects walking on the soil surface; *third row left*, solar bait station for early detection of wireworms; *third row right*, suspended black ball coated with adhesive for capture of tabanid flies; *bottom left*, red sphere on yellow panel coated with adhesive for detection of apple maggot flies; *bottom right*, boll weevil trap.**

Traps for Capturing Insects, Figure 98 **Additional insect traps: *top left*, grain probe traps for detection of stored grain insects; *top right*, blacklight trap for detection of nocturnal flying insects; *second row left*, wing trap, a lure-based trap with a sticky interior for sampling flying insects; *second row right*, wasp trap, a food lure-based trap; *third row left*, unitrap, a popular pheromone-based trap for capture of moths; *third row right*, a bucket trap baited with pineapple and pheromone for capture of palm-infesting weevils; *bottom left*, a cylindrical yellow panel coated with adhesive for detection of flying insects; *bottom second from left*, New Jersey light trap for capturing mosquitoes; *bottom third from left*, mosquito emergence trap; *bottom right*, McPhail trap, a food lure-based trap for capture of fruit flies.**

large insects, sticky material such as Tangle-trap is applied to the surface. The traps can be serviced by using a small tool to scoop insects of interest off the trap and onto a card, or the entire trap can be replaced. For transport, the panel with sticky material can be covered with clear plastic wrap or the panel can be placed in a box with spacers to keep panels from touching other surfaces. To reuse the trap, a paint scraper or thinner can be used to remove sticky material from the surface so that new material can be applied. The advantage of this trap is that it is inexpensive and will capture a variety of insects that are moving through the area. The surface area and trap orientation can be increased by using two panels that are crossed into baffles. The primary disadvantage is the trap can be very messy, can become coated with dirt or debris and will no longer capture insects, and the sticky material is difficult to remove from the captured insects. These traps, as well as other traps for flying insects described below, are usually placed above the ground at the height of the vegetative growth. When used in row crops, the traps usually are attached to a wooden or metal stake, and the traps are moved higher as the plants grow over the season. When used in trees, traps are normally hung within the canopy. Trap placement and orientation within the canopy, as well as amount of vegetation near the trap, will vary among the trap types and target species.

Three-Dimensional Triangular Traps, Diamond Traps and Wing Traps

This group is another set of fairly inexpensive traps that are used with an attractant. These are basically sticky traps with the sticky surface protected on the interior of the trap and are either disposable or used with a sticky component that is replaced at servicing. Delta traps are small and light-weight triangular (tent-shaped) traps that are easy to hang in trees and to transport. The Jackson trap is a delta trap used for a number of tropical tephritid fruit flies. It has a removable base coated with sticky material that can be replaced at time of sampling. Diamond-shaped (in profile) traps are used to monitor indoor pests in public areas, such as stores and supermarkets. Wing traps composed of a roof and a floor are used for pest Lepidoptera. These are larger and more cumbersome than delta traps, but the larger surface is more suitable for larger pest moths. Because the sticky surface is enclosed, these traps are less susceptible to dirt and dust and capture fewer non-target insects than sticky traps, but the surface still may be coated with dust or debris that gets blown into the trap.

Water Pan Traps

A simple collection method for aphids and other small flying insects is a water pan trap. Insects flying over the trap are attracted to the reflective surface of the water and are captured. The traps are made from rectangular baking pans, storage containers, or dish-washing pans partially filled with aqueous solutions of soap or car antifreeze. Care should be used in selecting soap to be used so that it does not contain odors that may be repellent to target insects or that the antifreeze is environmentally safe. (Most antifreeze solutions are poisonous, and traps containing antifreeze should be placed so that animals are unable to gain access to them.) These traps are open containers, so there may be problems with movement in wind, evaporation during dry periods or overflowing during periods of heavy rain.

Bucket Traps

Another simple and inexpensive trap is a bucket trap. The bucket trap may be used without a lid, or as a closed container with holes on either the top or sides for insects to enter. Small drainage holes may be placed near the bottom of the trap to allow trapped water to drain out. The Nadel trap and Mission trap are examples of bucket traps that are translucent closed containers with entrance holes around the periphery. The corn rootworm trap has a large dome-shaped top and a gap between the top and the container. Size of the container and placement, diameter and number of entry holes is dictated by the targeted insect. These usually are used with a chemical lure of some type. These may be used without a killing agent so that live insects can be recovered, however captured insects may escape through the entrance openings. A variety of retention devices can be used with bucket-type traps. A pesticide such as dimethyl 2,2-dichlorovinyl phosphate (DDVP, mothballs) can be used inside, but if the concentration is too high it may prevent insects from entering. Aqueous solutions of soap or car antifreeze or surfactants such as triton may also be used. Again, care should be used in selecting soap that does not contain odors that may repel target insects and/or environmentally safe antifreeze should be used. Sticky material may also be used on either the interior or exterior surface. When used on the exterior, this may increase effectiveness of lure-baited traps because usually only a proportion of the insects attracted to the trap will proceed to enter the trap. However, the same problems outlined above for sticky panels will apply to sticky-coated bucket traps. Open-bottom cylindrical traps are essentially bucket traps used upside down. The Phase 4 trap is a green cylinder that uses a yellow panel as a sticky insert to retain captured insects. Clear versions of the trap have also been used. In addition to the opening on the bottom of the trap, entrance openings also are located around the periphery of the cylinder.

Bucket Traps with Funnels

Probably the most common traps for agricultural use are combinations of bucket traps with funnels. They are more costly than simple bucket traps and they are often used with some type of odor attractant. The funnel essentially provides an enlarged hole that directs movement of the attracted insect into the bucket. There are differences among this group of traps in orientation of the funnel and size of the funnel in relation to size of the bucket. The Steiner trap is a clear plastic horizontally oriented cylinder with small funnels centered on the flat sides of the cylinder. For insects that approach from the underside of the trap and move upward, the funnel is used with the large opening facing downward and the small opening leading up into a bucket or other container. Because it is difficult for the insect to find the top of the funnel for exiting, and these insects tend to move upward, they can be used with or without a pesticide or liquid to retain the insects. A well-known example of the downward facing trap is the McPhail trap, which is a bell-shaped invaginated trap that is used for tephritid and drosophilid fruit flies. The original trap was made from glass and there are several plastic versions of McPhail-type traps available including dome fruit fly traps, International Pheromones McPhail traps and Multilure traps available that typically have a clear top and a yellow base. Another example is a wasp trap, such as the Victor yellowjacket trap. This trap has holes around the sides of the base for wasps to enter, and then a funnel that leads to a separate upper container that retains the wasps.

Other insects approach from the top and either move or fall downward. For these insects, bucket traps with funnels that have the large opening facing upward and the small opening leading down into the bucket are appropriate. The universal moth trap (unitrap) and Multipher trap are examples of this trap and they commonly are used for Lepidoptera adults. These traps have lids held above the funnel opening to shelter the contents from rain and are available in a variety of colors. A trap developed for the Japanese beetle, *Popillia japonica* Newman, uses a funnel with the large opening facing upward and the small opening over a container, but the funnel is topped by two panels crossed to form a baffle. Insects are intercepted by the baffles, fall into the funnel and are captured in the container. The boll weevil trap is a version of a bucket trap that contains a funnel mounted on a cylinder. Insects land on the cylinder and move up the sides of the trap, enter the funnel and move into the small collection bucket above the small funnel top. The Lindgren funnel trap consists of 4, 8 or 12 plastic funnels stacked vertically over the container. It is used for ambrosia beetles and bark beetles. Fast-flying beetles hit a funnel and are deflected down into the collection container.

Cone Traps

Cone traps are essentially bucket traps with funnels, but the funnel is very large in relation to the size of the bucket or collecting tube. These are used with the large opening of the funnel oriented toward the ground and the top of the funnel leading up to a container. Examples of these traps include *Heliothis* traps and butterfly bait traps. These traps are made from a light cloth or mesh material and the design takes advantage of the moth or butterfly's tendency to move upward. The butterfly bait traps have a large container for the butterfly to move into so that the insect is undamaged.

Traps for Walking Arthropods and Soil-Dwelling Insects

Pitfall Traps

Pitfall traps are useful for collecting insects and other arthropods that are walking across a surface. This surface is usually a soil surface, for capturing beetles, spiders and other ground-dwelling organisms, although they also may catch flying insects that are walking across the soil surface. Pitfall traps placed into the top of stored grain also have been used to sample stored product insects. Pitfall traps consist of a container that is buried in the substrate, and into which insects and arthropods fall and are captured. The traps used in soil consist of an upper funnel, a collecting container, and perhaps a liner that makes servicing easier. Upper funnels can be made from disposable plastic funnels with the bottoms removed to enlarge the hole. Collecting containers can be made from plastic cups, and can be designed for dry catches with screens in the bottom to permit rain water to flow through, or can be made to hold a glycol (antifreeze)/water/detergent solution. Dry containers need to be serviced several times a week to minimize destruction of the sampled insects from other insects entering the trap. They have the advantage of providing live specimens for further studies. Wet containers can be serviced at longer intervals, but have the disadvantage of filling with rain water. Traps should be designed to produce minimal impact on the nearby soil, because insects may be repelled or attracted to the disturbance. To do this, holes can initially be cut with golf-hole cutters and lined with 4″diameter polyvinylchloride (PVC) pipe. The top of the pipe should be carefully leveled with the soil, and the traps serviced without disturbing the soil. Covers can be installed over the top to prevent rainfall from entering. Enhancement-fences or guides can be installed to guide insects to the trap. A cone with a gradual slope and smooth edge is necessary because insects may back away from the void of a direct hole. Captured insects should be removed at least weekly (wet) or twice weekly (dry).

Grain Probe Traps

Grain probe traps are a special modification of a pitfall trap for use in stored grain. Grain probe traps consist of an elongated cylinder with holes drilled into the sides that are above a funnel and insect receptacle. An early version of the trap was machined from solid brass and included a hollow cylinder made from 14 gauge brass sheet. Subsequently, probe traps have been made from clear polycarbonate (Lexan) plastic and from a perforated section of tubular polyethylene. The receptacle is coated with liquid Teflon (polytetrafluoroethylene) to prevent captured insects from escaping, however, insects remain alive for a while and may damage previously captured insects. These traps may be used at any depth within the grain mass, with long rods used to push the traps into place. A rope connected to the trap is affixed to the roof of the grain bin to allow removal of the grain probe trap and to prevent loss of the trap during grain bin filling and emptying operations. Traps should be inspected at 1–2 week intervals to remove the trapped insects. The PC trap is a cone-shaped trap that usually is used on grain mass surface, although it too can be pushed into the grain mass as long as it remains in an upright position. The top is covered by a convex lid that is covered with concentric circles of small holes to allow insects to enter the trap. When used at the grain surface, the traps are easy to remove for servicing, but webbing produced by larvae of lepidopteran grain pests, such as the Indianmeal moth, may block the openings into the trap and render them ineffective.

Shelter Traps

Shelter traps are used for insects that prefer a dark harborage and are useful in areas where it is preferred that the trap be inconspicuous. These are usually used to intercept insects as they walk over a surface and have small openings that encourage insects to enter the trap. Roach motels are the most well-known examples of such traps. They usually have a sticky material inside to trap insects that have entered or contain an oil or other substance to retain attracted insects. Shelter traps are used for stored product insects, and designs include dome traps, stealth traps and corner traps. The PC floor trap has been modified from the PC trap for use as a shelter trap by replacing the cone-shaped bottom with a flat container, which allows the trap to be placed on the ground or hung on a wall. Swarm traps are shelter traps that are used to capture unwanted swarms of domestic honey bees and to detect invading swarms of Africanized honey bees. These traps are fairly large bucket-shaped traps made of molded fiber material, have a single entrance hole, and are hung at least one meter above the ground. They provide a nesting site for bees, and the captured bees can be kept alive and moved to standard bee hives for honey production or pest bees can be identified and destroyed.

Emergence Traps

Emergence traps are a type of cone trap used for capturing adults that have subterranean larval and/or pupal stages. These traps are made from aluminum screening shaped into a funnel, with the top opening leading to a collecting tube or vial. The trap is placed flush with the ground and soil is pushed up around the edges to seal the trap to the ground. Adults emerging from below-ground stages move up into the trap and are captured in the collecting tube. The number of insects per unit area can be determined and the source of infestations can be identified. However, these traps may interfere with ground maintenance activities that prevent use in certain situations. Circle traps are another type of emergence trap. They are wire cone traps that are attached to the trunk or branch of a tree. Insects moving up a tree are captured, and because the traps are off of the ground, they do not interfere with ground maintenance activities.

Solar Bait Stations

The above traps can be used to capture the above-ground stages of subterranean insects, however the below-ground stages of wireworms (Elateridae), and false wireworms (Tenebrionidae) can be captured with solar bait stations. These are used to estimate wireworm populations and to make decisions on seed treatment/non-treatment. Larvae of these insect groups can be concentrated by creating microenvironments that have favorable moisture, temperatures, and food. A handful of grain (wheat, etc.) is buried a few inches below the surface of the soil. The bait is covered with a mound of soil, about 18″ high, and is covered with clear plastic. Edges of the plastic should be covered with soil to prevent them from blowing away. Stations should be constructed in the fall before soil freezes, and they can be examined in the spring before planting time. Surveyors' flags can be used to mark sites for easy location.

Traps for Aquatic Insects

Interception Traps

Interception traps capture aquatic insects moving through the water and are generally similar to interception traps used for wind-borne insects. Often, these traps are tapered nets with either round or rectangular openings which can be fixed in place to sample insects in moving water or pulled through the water manually. The size of the mesh governs the size of insects retained, but use of too fine a mesh may impede movement of water through the trap and retain too much debris.

Emergence Traps

Floating emergence traps are used to capture insects with aquatic larval stages when they emerge as adults. Construction and use is similar to that for emergence traps used for soil-dwelling insects.

Attractant Cues

Attractant cues are signals that are used by insects to locate resources for feeding, members of the opposite sex for mating, and oviposition sites for egg laying. Cues are added to traps to increase insect specificity and effectiveness of the traps. Attractive cues from natural substrates may be perceived by one or several of the senses including sight, sound, and smell. Semiochemicals are naturally occurring, message-bearing chemicals that are used by insects (and other organisms) for communication and for perception of their environment. Semiochemicals that have a behavioral effect on insect orientation, that is, chemicals that cause an insect to move toward the source, are used in insect traps. Of specific interest are kairomones, which are signals emitted and received by members of different species (interspecific) that give an advantage to the receiving species, and pheromones, which are signals emitted and received by members of the same species (intraspecific). Traps may use single cues to lure insects, but often a combination of cues is used to improve insect capture. For each cue and each insect species being targeted, there is usually an optimal range of stimulus intensity, below which attraction is minimal and above which attraction is reduced. Control of the stimulus level is particularly important for semiochemical cues, and considerable research has been conducted to optimize emission rates and ratios of semiochemical blends. This effect seems less important for acoustic cues, where it has usually been determined that the greatest capture rates are found for traps with the highest sound levels.

Visual Cues

Color

Color can serve as a strong attractant for use in a trap. Insects may use a specific color to locate host fruit or plant material, with both hue and intensity affecting insect response. Contrasts between light and dark can also play a role, with either the trap in contrast with the background color or through the use of lines with insects orienting to an edge between a light and dark area on a trap. Most sticky traps use a color to target certain insects. Yellow is the most commonly used attractant color, and is used to capture hemipterans such as whiteflies and aphids, but is also used for almost every order of flying insects. The Rebell trap is constructed from two yellow panels as baffles, and is used for walnut husk flies, *Rhagoletis completa* Cresson, and cherry fruit flies, *Rhagoletis cingulata* (Loew). A disadvantage of using yellow for sticky traps is that it also attracts beneficial insects such as hymenopteran parasitoids, and the traps may fill up with these and other non-target insects. Yellow-colored pan traps are used to capture Hymenoptera, especially the parasitoid species. Orange sticky traps are used for carrot rust fly, *Psila rosae* (Fabricius), and blue sticky traps for western flower thrips, *Frankliniella occidentalis* (Pergande). Blue is also highly attractive to tsetse flies (Glossinidae). White sticky traps are used as panels and as trunk wraps for capture of tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois), and eastern apple sawfly, *Hoplocampa testudinea* (Klug), and red trunk wraps for apple blotch leafminer, *Phyllonorcycter crataegella* (Clemens). Use of contrasts may increase insect capture, such as the use of insect silhouettes added to the surface of white sticky panels to increase capture of house flies, *Musca domestica* L.

Shape

Shape can be used as an attractant, although it is combined with appropriate color for the target insect. Spheres commonly are used as traps for tephritid fruit flies. Red spheres are used for apple maggot flies, *Rhagoletis pomonella* (Walsh), small green spheres for blueberry maggot flies, *Rhagoletis mendax* Curran, and large green spheres for papaya fruit flies, *Toxotrypana curvicauda* Gerstaecker. A Ladd trap is a red sphere that is mounted on a yellow panel and is used for apple maggot flies and cherry fruit flies, *Rhagoletis cingulata* (Loew). Black spheres have been used to capture biting flies in the family Tabanidae, which are attracted to the movement of the black ball hanging in a tree. A tree silhouette is mimicked by a Tedders trap, which is a baffle constructed from two dark isosceles triangles, with the unequal side forming the base. The size of the Tedders trap can be adjusted to optimize capture of tree-dwelling beetles. Root-infesting weevils, such as pecan weevils, *Curculio caryae* (Horn) and several citrus root weevils, as well as wood-boring beetles, may be captured by these traps. Beetles emerging from soil or moving along the soil surface respond to the trap as if it were the trunk of a tree. The insect moves up the baffles and is captured in a small collection container at the top of the trap.

Light

Attraction of insects to light is easily observed by standing next to a porch light or street light during the night. A commonly accepted explanation of this phenomenon is that insects have evolved mechanisms to travel straight paths at night by orienting at a constant angle to the light of the moon. Artificial light produced by man-made devices interferes with this response. Moving at a constant angle to a light source always directs the insect toward the source of the light, once it comes within a few meters. Lights that include ultraviolet (UV) frequencies may also be attractive because insects in a confined area can use UV light as a cue to the direction of an opening into a clear area. A variety of insect traps have been developed and used that are based on a light as the attractant. Lights used include mercury lamps and black lights (UV) for moths, incandescent lights for flies and mosquitoes, green lights for stored product insects and cyalume lightsticks for aquatic light traps. Light traps, also called electric traps, are typically bucket traps with funnels. When used with fluorescent bulbs, the traps have baffles alongside the bulb that knock insects attracted to the light down into the trap. The Pennsylvanian light trap is an example of this design. Rothamsted and Robinson-type traps use incandescent bulbs with a reverse funnel over the light bulb. The New Jersey trap and the CDC trap are light traps developed for mosquito surveillance. They use incandescent bulbs, a fan that creates a suction to draws attracted mosquitoes down into the bucket and a filter to prevent larger insects from entering the trap. Lights may also be used with sticky traps to retain attracted insects. These more commonly are used for control of indoor pests such as house flies, stored product insects and fleas. A LED-CC trap for whiteflies uses a green light-emitting diode (LED) to attract insects into an open-bottom clear cylindrical trap with a yellow ring on the bottom.

Chemical Cues

Food/Host Lures

Volatile chemicals emitted from host plants, animals and other materials are used by insects to locate food sources. These chemicals are referred to as kairomones, that is, chemicals produced by a plant or animal that are advantageous to the receiving individual of a different species. Host material can be used to bait traps for insect capture, and the spectrum of use of food-based baits for insect control and pest management are covered in separate chapters. Examples of use of host material in a trap include use of carrion in pitfall traps or fruit in butterfly bait traps as survey tools, or fruit and meat in traps for yellowjackets (Hymenoptera). Grain or grain products (e.g., wheat germ, wheat germ oil, corn oil, etc.) are used for stored product insect pests, and grain oils used in shelter traps provide both an attractant and a method to kill attracted insects. However, host material may rapidly decay or may release attractive chemicals for only a short time period after initial placement. The insect may be using only a few of the sometimes numerous volatile chemicals emitted by a host and traps baited with synthetic chemical versions of the host can be used to lure an insect into a trap. The quality and quantity of the chemical can be controlled by the method of formulation, providing a standard release rate for a known time period, which improves trap performance. Carbon dioxide is used by mosquitoes to locate vertebrate hosts, and addition of dry ice to a trap can be used to survey blood-feeding mosquitoes. Octenol (1-octen-3-ol) is a naturally occurring chemical emitted by oxen and cows because they ingest large amounts of vegetable matter, and combinations of octenol and carbon dioxide are used to bait traps for mosquitoes, biting midges and no-see-ums (Ceratopogonidae). To make these chemicals more attractive, they can be combined with heat and moisture in a trap such as the Mosquito Magnet. Host kairomones are used with blue sticky traps to capture tsetse flies and in rootworm traps for corn rootworm adults. Floral cues are used in traps for Japanese beetles, and for nectar-feeding female moths (Lepidoptera). These are used in bucket traps with funnels. Fruit lures that provide volatile chemicals emitted from apples and plums are used in traps for apple maggot flies and for plum curculio, *Conotrachelus nenuphar* (Herbst). Fruit lures for apple maggot flies are hung near red sphere traps; fruit lures for plum curculio are used in a variety of traps, including Tedders, circle and boll weevil traps. McPhail-type traps can be used with a variety of liquid baits. They have been used with fermenting sugar solutions to capture small fruit flies (Drosophilidae) and moths (Lepidoptera), and with aqueous protein solutions for fruit-infesting fruit flies (Tephritidae). Ammonia has been found to be the primary chemical responsible for attraction of tephritid fruit flies to protein solutions, and ammonia alone or in combination with other synthetic volatile chemicals emitted from protein baits are used in sticky panels, sticky spheres or McPhail traps to catch these fruit flies.

Pheromone Lures

There are two main types of pheromones that are used with insect traps. Sex pheromones are produced by one sex to attract the opposite sex. The sex pheromones most commonly used in traps are ones that are produced by females. These are used in either wing traps or bucket with funnel traps, and there are lures available for numerous species of pest Lepidoptera and for sweetpotato weevils, *Cylas formicarius elegantulus* (Summers). The moths tend to be active at night, so visual cue is less important, however, the contrast of a white or light colored trap versus the dark background often increases capture. The advantage of traps baited with these sex pheromones is that they are highly specific and very effective, however, they capture only males and so no information on or samples of females are obtained. Some male tephritid fruit flies produce a sex pheromone that is attractive to female flies, and the papaya fruit fly pheromone increases capture of both male and female flies on green sticky sphere traps.

Aggregation pheromones are used with insect traps also. These are attractive to both sexes and are used to bring both sexes to a common location for both feeding and mating. Although both males and females can be captured in traps baited with aggregation pheromones, they tend to be less effective lures than sex pheromones or they need to be presented with other cues. Exceptions are the pheromone produced by boll weevils (Grandlure), *Anthonomus grandis grandis* Boheman, and the lesser and larger grain borers, *Rhyzopertha dominica* (Fabricius) and *Prostephanus truncatus* (Horn). Sticky, shelter and wing traps baited with these pheromone lures capture both sexes of these borers. Aggregation pheromones are often produced by males in conjunction with feeding, thus since both insect pheromone and host kairomones are emitted as signals, both are needed to elicit attraction. Combinations of synthetic aggregation pheromone and host material as source of kairomones are used in shelter traps for stored product beetles and cockroaches, in Lindgren or panel traps for bark beetles, and in bucket traps for palm weevils. A combination of honey bee pheromones is used in swarm traps to increase bee capture. This includes honey bee queen mandibular pheromone (BeeBoost) and an orientation pheromone produced by worker bees (Nasonov).

Parapheromone Lures

Parapheromones are a special group of lures that are used to trap some species of tephritid fruit flies. They act as sex pheromones because they are highly attractive to male fruit flies, similar to female-produced sex pheromones. However, these are not insect-produced compounds and do not appear to play a dominant role in the biology of the responding species. They may be synthetic kairomones, as they are similar in structure to some plant compounds, and access to the synthetic or natural versions of these compounds have been shown to increase sexual competitiveness of males. These compounds include trimedlure for Mediterranean fruit flies, *Ceratitis capitata* (Wiedemann), cuelure for melon flies, *Bactrocera cucurbitae* (Coquillett), and methyl eugenol for oriental fruit flies, *Bactrocera dorsalis* (Hendel). These lures are most commonly deployed in white Jackson traps (triangle traps) or on yellow sticky panels.

Oviposition Lures

Oviposition lures are chemicals that attract egg-laying (gravid) females. A gravid mosquito trap uses a baited water solution to attract and capture the adult females. A trap and bait also has been developed for navel orangeworms, *Amelyois transitella* (Walker), on which the female moth lays eggs.

Acoustic Cues

Just as many insect species produce volatile chemicals to attract members of the opposite sex, some species use sound alone or in combination with chemicals for this purpose. Such cues have been incorporated successfully into panel or bucket traps of several different shapes. The different sounds broadcast as attraction cues have included songs recorded from conspecifics of the targeted insect and synthetic mimics of the songs. A variety of different speaker systems have been used, including standard loudspeakers, piezoelectric boards with extensive surface areas, and piezoelectric cylinders.

The most successful use of acoustic traps has been for mole cricket (Gryllotalpidae). Sound traps have been developed that produce highly amplified synthetic or recorded calls of male mole crickets. A bucket or bucket with funnel trap is placed under the sound emitter to capture responding crickets. These traps also capture tachinid flies that parasitize adult crickets and that locate them by responding to the call. Sticky traps broadcasting the recorded male lesser wax moth, *Achroia grisella* (Fabricius), calling song have been used to attract virgin females. Many tephritid fruit flies perform wing-vibration behaviors during courtship, and there have been a few attempts to attract female fruit flies by broadcasting songs recorded from courting males. Such songs have been demonstrated to be attractive to Mediterranean fruit flies over distances of 50 cm or less, but the traps are noisy and require electric power. Jackson traps broadcasting the recorded male Caribbean fruit fly, *Anastrepha suspensa* (Loew), calling song have been demonstrated to attract virgin females.

Another use of acoustic cues is as an attractant for males of some midge and mosquito species that form swarms to attract females. When females fly into a swarm, the males are attracted by their wingbeats, which are of distinctly lower frequencies than those of the males in the swarm. Consequently, males can be attracted in great numbers by placing a black cloth or other swarm marker on the ground and broadcasting recorded or synthetically generated female wingbeats from a speaker inside or at the edge of a sticky panel, cylinder, or cup hung about 1 m above the swarm marker. Acoustic traps can greatly reduce male populations of sedentary mosquito species, and also have been used to chemosterilize and re-release males rather than killing them. However, they are not yet in common use in isolated field environments because they require electricity and some technical skill to operate, and the sound that must be broadcast at high amplification for optimal trap catch can be a nuisance.

Automated Monitoring Systems

Advances in information technology, computer technology, and remote sensing are adding to the field of precision agriculture; that is, use of computers to aid in management decisions. The ability to rapidly move data from traps into computer databases or spreadsheets is an integral component of precision agriculture, and will facilitate making pest management decisions in a timely manner. Bar codes can be added to traps and a bar code scanner can be taken to the field to expedite data entry on trap type, trap location, etc., so that only insect counts need to be entered manually. In addition, data can now be transmitted by cable or wireless devices directly to a local computer for later downloading, or data can be transmitted to an off-site computer. Ideally, the tasks of species identification and counting would be automated to eliminate expensive, time consuming labor. This ideal has not yet been realized to any practical extent, although it is a goal of considerable interest to agricultural engineers and entrepreneurs.

A potential method for automating the insect identification process is to analyze the wingbeats of insects coming into a trap or flying overhead. Fourier transforms, nearest neighbor classification, and artificial neural network classification schemes have been tested in feasibility studies with aphids and mosquitoes, and species classification accuracies of up to 70–90% have been reported. If the costs of hardware needed to detect and transmit wingbeat sounds continue to decrease, automated identification will soon emerge from the laboratory as a practical option in environments where traps are difficult to service or labor costs are prohibitive. An example of counting insects where traps might be difficult or dangerous to service is a device to evaluate the intensity of honey bee defensive attacks near a hive. The device includes a microphone set inside a plastic target, connected to a datalogger with an amplifier, tone decoder, and a microcontroller that times and stores information from the decoder continuously, and later transfers data to a personal computer. For operation, the target is moved next to the hive and the hive is disturbed. The bees attack the target with sharp blows that are counted and saved for downloading after the attack is over.

Another already existing approach to automated off-site monitoring is the use of gravimetric analysis of flight trap captures of red flour beetles, *Tribolium castaneum* (Herbst). Beetles responding to cone-shaped flight traps fall into a small container coated with liquid Teflon which rests on the weighing pan of a digital pan balance. Signals from the balance are sent over a cable to a personal computer, and the weight, which is recorded at sequential intervals, is used to estimate the numbers of insects captured over time. Insect movements that interrupt an infrared light beam can be counted by a computer that monitors fluctuations in the beam intensity. Infrared beams can be used in actigraphs to monitor insect movement in activity chambers. Infrared beams also are used in a recently developed electronic grain probe insect counter system. The beams are located below the bottom of the funnel in a cylindrical grain probe trap. Insects falling through the funnel are counted electronically and time-stamped data is transmitted to off-site computers. Counts from electronic traps along with information from automated temperature and relative humidity probes can be collected together and used for management decisions.

Trap Uses in Integrated Pest Management (IPM)

The goals of trapping are highly variable. Traps may be used for general survey of biota, for detecting the start of population increase in infested areas, for identifying the source of stored product pest infestation in a store or warehouse, or for detecting invasion by exotic invasive insect pests in previously uninfested areas. Trapping systems for insects are important components in integrated pest management programs. Trapping data can be used to make decisions on the initiation or termination of control measures, as well as to assess efficacy of control approaches that have been implemented. Detection trapping is used to alert personnel to the presence of a new insect pest in a previously pest-free area so that control measures can be implemented in a timely manner. Early detection and targeting the locations of small infestations will facilitate pest management strategies such as biological control or sterile insect technique that are most effective when pest populations are low. With the availability of sufficiently effective traps that capture both female and male pest insects, trapping systems may be used as control measures, and thus could be added to the growing list of biologically based technologies for insect control. Traps can be used as toxicant delivery systems, with insects that visit the trap taking a slow-acting poison back to the rest of the population. This approach is used with social or gregarious insects such as termites, ants and cockroaches. Mass-trapping is the use of large numbers of traps in an effort to suppress the population. Sticky traps are usually used in this approach as a high percentage of responding insects are captured. This approach has been used to suppress populations of a pest such as apple maggot flies and papaya fruit flies, which spend part of their life cycle away from the host and can be intercepted by traps placed around the periphery of the orchard. However, these traps require frequent servicing to maintain activity. An alternate approach is the development of attract-and-kill systems, sometimes called attracticides. In this approach, insects responding to traps consume or contact a toxicant, but then exit the trap and die away from the trap. Examples include addition of insecticide to artificial cows for control of tsetse flies, methyl eugenol mixed with insecticide for control of oriental fruit flies, addition of insecticide to pheromone to control codling moth in apples, and addition of insecticide to feeding stimulant in corn rootworm traps. All of these control approaches should be combined with other pest management strategies to be fully successful.

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Traumatic Insemination

A form of insemination practiced by bed bugs (Hemiptera: Cimicidae) and some other bugs wherein the male punctures the female's abdomen with his needle-like penis and deposits sperm within her hemolymph; they then migrate to her ovary to fertilize the eggs. This is also called "hemocoelic insemination."

► Bed Bugs

Tree Crickets

A subfamily of crickets (Oecanthinae) in the order Orthoptera: Gryllidae.

► Grasshoppers, Katydids and Crickets

Trehalose

A polysaccharide found in insects that is one of the two most common carbohydrate stored reserves (the other is glycogen) for insect flight. It occurs principally in the hemolymph, fat body, and gut tissues. Trehalose is usually the first metabolite used when energy is needed. Each molecule of trehalose is hydrolyzed into two molecules of glucose. Trehalose also is rapidly synthesized from glucose as it is absorbed in the midgut. Glucose is not usually present in high concentrations in the hemolymph because of this synthesis, so glucose absorption is easily accomplished.

Treherne, John E

John Treherne was born on May 15, 1929, near Swindon, England. He was educated at Bristol University. After military service he was invited by Vincent Wigglesworth the join the Unit of Insect Physiology at Cambridge. Treherne did so, and also served as lecturer and reader at the University. Upon Wiggleworth's retirement, Treherne headed up a new Unit of Invertebrate Chemistry and Physiology at Cambridge. Treherne's reputation was based on research of insect neurobiology, the blood-brain barrier of insects, gut physiology, circadian rhythms, hormones, cuticle permeability, osmoregulation, and other physiological subjects. His subjects were not just insects, as he worked on molluscs and annelids. Indeed, he was a physiologist first and foremost, and never pretended to be an entomologist in the classic sense. Nevertheless, he enjoyed field entomology, especially marine and salt marsh insects, and made insightful behavioral and evolutionary contributions in this area. Treherne served as editor of "The Journal of Experimental Biology," and edited "University Reviews of Biology," "Advances in Insect Physiology," and others. He served as president of Downing College from 1985 to 1988. Treherne also wrote popular novels, some of which included entomological elements. He died on September 23, 1989.

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Treehoppers (Hemiptera: Membracidae)

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Most treehoppers are readily distinguished from their close relatives, the leafhoppers, by their