LEAST TOXIC PEST CONTROL: HOW INFESTATIONS OF TERMITES, ANTS, FLEAS, TICKS, AND BEETLES CAN BE CONTROLLED WITHOUT CAUSING SHORT- OR LONG-TERM INDOOR AIR QUALITY CHANGES AND HEALTH RISKS

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ABSTRACT

A number of least-toxic measures are discussed within the framework of integrated pest management systems for termites, ants, fleas, ticks, and beetles. It is presumed that adherence to such programs minimizes changes in indoor air quality and also reduces health risks by eliminating use of traditional, often hazardous pesticides. Emphasis is placed on preventative measures such as habitat modification and resource removal to eliminate conditions that encourage the establishment of and foster the growth of pest populations within the home. Control tactics are broadly categorized as chemical, biological, and physical, and are detailed in light of pertinent advances in research. Techniques relate directly to the biology of the organisms and target periods of vulnerabilty, symbiotic relationships between the pest and other organisms, and basic physiological processes. Boron formulations, insect growth regulators, and the use of extreme temperature seem to have the most widespread applications, although "neem" products may soon surpass even these advances.

INTEGRATED PEST MANAGEMENT

Modern synthetic pesticides were first used during World War II. Their effectiveness was great compared to that of previous methods and their potential seemingly unlimited since minimal hazard levels were perceived. Pest control operators quickly came to depend on soil chemicals and "calendar" spraying, often treating at the first sign of a pest with little or no evaluation of the employed system. Exclusive reliance on chemical controls has lead to a number of problems. One is the development of resistance by the pest. First noted in cockroaches, flies, and mosquitoes, resistance is now found in over four-hundred species of pests. Indiscriminant use of certain chemicals has actually selected for survivors in pest populations and has permitted establishment of resistant progeny.

Another problem is resurgence. Non-selective pesticides can remove the natural enemies of target pests and cause pest populations to skyrocket. Similarly, elimination of the natural enemies of <u>potential</u> pests can lead to secondary pest outbreaks. Residues left by some pesticides also affect non-target organisms and can build up in the food chain. Further, these residues can be involved in synergistic phenomena in which the insecticide combines with environmental factors that actually increase its toxic effect.

Increased public concern over the use of insecticides and the political organization of people affected by insecticides or their residues pose a substantial hurdle for the continued use of certain chemicals. Moreover, regulations regarding the application of pesticides are becoming more stringent. Non-renewable fossil-fuel, necessary for the manufacture and application of synthetic pesticides, is in higher demand and the cost of implementing traditional methods is rising as budgets for control are declining. Fortunately, alternative measures in pest control have been developed and there are a number of ways to rationally and inexpensively combat pest problems. Given the commercial availability of these newer techniques, traditionally-used chemicals can be considered "last resorts"; to be employed when alternative tactics fail and applied in a discrete way so as to minimize exposure of non-target organisms.

Integrated pest management (IPM) is a decision-making process in which one first determines if a pest suppression treatment is necessary and, if so, answers questions regarding when, where, and with what. It involves prediction of economic, ecological and sociological consequences. In agricultural settings, IPM programs have been developed for a variety of crops. Pesticide use on these crops has dropped significantly, while yield and quality have been retained, even improved. In urban environments, IPM has been used to manage pests in parks, gardens, and in many types of buildings. IPM concepts have also been employed in forests when cyclic outbreaks of wood damaging insects and diseases have occurred. While the term "IPM" has gained popularity, it has also been misused by institutions and pest managers eager to jump on the bandwagon pulled by enthusiastic consumers.

To clarify the meaning of the phrase, it is first necessary to define the term "integrated". In part, the word implies the fitting together of different treatment strategies into a total management program. On this basis alone, many companies claim to offer IPM programs. The definition is actually more complex, since IPM programs are not mix-moshes of biological, chemical and physical controls. Rather, the components are organized through both monitoring and evaluation procedures, and careful decisions are derived through consideration of economic, medical, and aesthetic aspects of the treatment procedure. When IPM programs are designed, interactions between key pests, their natural enemies, potential pests, and other living and non-living factors are also weighed.

In addition, IPM practitioners view pest management as a single component within the context of ecosystem management. That is, social, economic, political, and ecological factors all influence pest management decisions. Aesthetic concerns of the public are also considered, as well as government regulations applicable to product marketing. IPM programs are consequently transdisciplinary, relying on a variety of sources for input. Contributions come from entomologists, plant pathologists, soil scientists, architects, public health professionals, sociologists, economists, etc. Essentially, information obtained by IPM practitioners is woven into a coherent site-specific strategy which aims at balancing the relationship between humans and the species they regard as pests. It is the flexible nature of IPM programs that make them so economically and aesthetically sound. The use of natural pest controls such as disease agents, predators, and parasitoids is maximized and artificial controls are instituted only when pest populations threaten to exceed a predetermined level of injury.

The objective of IPM programs is not to eradicate pests, but to suppress their populations below a level which causes unacceptable damage. It is generally desirable to permit a pest to remain at low levels so as not to drive away its natural enemies or to increase the risk of resistance development from prolonged insecticide use. Pesticides never kill all their target organisms; survivors go on to reproduce and pass along their ability to detoxify the pesticides that are used against them. Associated decreases in predator levels encourage the growth of these surviving populations. By far the most energy- and cost-effective pest management strategy involves consideration of the human system within which pests find their resources. Through appropriate building design and maintenance, and removal of food, water, and harborage sites, the establishment of pest populations can be significantly reduced.

There are six basic parts to an IPM program: (1) initial information gathering to identify the pest and the problem, and to delineate circumstances which may be contributing to the infestation; (2) monitoring at regular intervals to establish fluctuations in the pest population or changes in the environment; (3) establishing an injury level to predict if and when the pest problem will escalate to the point of requiring some sort of action; (4) record-keeping to note decisions made, actions taken, and results; (5) selecting least-toxic treatments which meet criteria regarding the least amount of hazard presented to non-target organisms and the general environment, and which are also economically-sound and likely to permanently reduce the area's ability to support the pest; (6) evaluation of the entire program to see how effective it is and if modifications should be made.

The terms "monitoring" and "injury level" also need to be defined. Monitoring implies regular inspections of areas in which certain pests are likely to be found and most importantly includes keeping records of the observations, paying attention not only to the target organism but also to surrounding influences such as human behavior and weather. Monitoring programs should be tailored to the particular situation, and the level of effort proportionate to potential damage, available time, and the monitor's skill. For example, monitoring a cockroach-infested kitchen may require only a bi-weekly inspection of sticky traps acting as population gauges. In larger systems such as forests and farms however, a more intensive monitoring program may be required. In certain situations potential pest and natural enemy populations are also monitored.

Key to the IPM concept is establishment of an "injury" or "tolerance" level to indicate whether or not a problem is serious enough to warrant treatment. The derived value takes into consideration the amount of economic and aesthetic damage that can be tolerated and is coordinated with a specific pest population level. In agriculture, the degree of pest damage that makes management worthwhile is relatively easy to determine. Similar determinations are more difficult to make for building infestations since opinions differ on tolerable levels of damage. For example, people respond differently when asked how much visibility of a pest or evidence of its activities is acceptable. An initial injury level must therefore be set for the given pest at the given site, but it should be noted that this level is subject to change as the program continues. When an injury level is suggested, it must be compared with field observations before action is taken. Any pest management operation that does not include periodic re-evaluation of injury level cannot rightfully be called an IPM program since unnecessary activities can waste resources and funds and can even exacerbate the existing condition.

The purpose of this paper is to detail least-toxic methods of prevention and control for termites, beetles, ants, fleas, and ticks. Since the underlying framework is implementation of IPM programs, each topic will be discussed with basic IPM questions and approaches in mind. Due to the site-specific nature of IPM programs, no exact prescription for control of these arthropods will be given. However, a general outline of steps in a least-toxic program is presented and a number of innovative techniques are cited or alluded to. Much research has been done involving the development of new insecticides, but because the focus has often been on agriculture indoor adaptations can only be suggested. I have therefore tried to concentrate on basic techniques used against the most common house-invaders. There are of course a number of pests that were not included in this discussion and moreover, a number of control techniques not mentioned or insufficiently described for the arthropods that are discussed. Unfortunately, it is beyond the scope of this preliminary review to focus on a broader range of approaches and target pests. A good deal of material applicable to our discussion awaits patent approval or scientific publication; preempting such disclosures would be inappropriate.

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TERMITES

I. Identification of problem

A. Introduction

The order Isoptera contains many economically important insects. There are six families which exist worldwide: Kalotermitidae (drywood termites), Termopsidae (dampwood termites), Rhinotermitidae (subterranean termites), Termitidae (mound-building termites), Mastotermitidae, and Hodotermitidae (harvester termites). The three families found in the United States are Kalotermitidae, Termopsidae, and Rhinotermitidae. The latter of these will be emphasized in our discussion.

B. Termites in their natural environment

In their natural habitat, termites are highly beneficial insects. They work along with decay fungi to break down dead or dying plant material, returning chemical elements in the wood to the soil. Their role in the nutrient cycle is therefore important, and attempts to control them need only be made when human possessions are attacked or threatened.

C. Termites as pests

Termites have become "pests" for a few reasons. In clearing forested areas for construction we remove cellulose, termites' natural food source. Wooden structures which replace lost plant material are then exploited as an alternative resource. The estimated value of wood-containing, single-family units in the United States was about 2.5 trillion dollars in 1980. This amount, plus the unknown value of multifamily units, government-owned buildings, and other wooden products, represents a significant portion of the United States's net worth and should signal prompt pursuit of wood preservation techniques.

Unfortunately, available, effective, and often inexpensive preventative treatments are neither widely nor consistently employed. Poorly designed slab-on-ground construction, increased use of concrete and masonry adjacent to foundation walls, and other home and yard alterations are often associated with lack of preventative measures, impairment of prior chemical treatment, and exposure of vulnerable surfaces. Factors such as these inflate the cost of control and unnecessarily deplete our valuable wood resources.

Of the 2,200 species of termites known worldwide, sixty-nine infest buildings. About fifteen species found in the United States damage human dwellings, community buildings, and various wood products. Subterranean termites are considered the most destructive and economically important family. They occur throughout the United States, except in Alaska, and are most numerous and destructive in warmer regions. The predominant subterranean termites are Coptotermes formosanus Shiraki, and species of the genera Reticulitermes and Heterotermes. Costs for damage and control of termites may exceed an estimated 750 million dollars annually, with subterranean termites accounting for about 95 percent of the total loss. Much of this percentage can be attributed to species of Reticulitermes which are widespread on the mainland. Heterotermes aureus (Snyder) is a major pest in the desert Southwest, and Coptotermes formosanus Shiraki attacks buildings in Hawaii (although it also damages structures in southern states).

The southeastern part of the United States is considered to be a "high hazard" area, with an untreated building having an 80-100 percent chance of being attacked by subterranean termites during its lifetime. The northern third of the United States is a "low hazard" area with structures running a 0-50 percent chance of attack. Other zones of the country are "moderate hazard" areas, with buildings having a 50-80 percent chance of infestation. These differences allude to the importance of understanding termite biology in order to predict activity patterns and select appropriate control measures.

The most destructive drywood termites occur in the southern and southeastern coastal states, and in Arizona, California, and Hawaii. They include Cryptotermes brevis Walker, Neotermes castaneus (Burmeister), and species of Incisitermes. The dampwood termites Zootermopsis angusticollis (Hagen) and Z. nevadensis (Hagen) damage wood in Oregon, Washington, and California. Paraneotermes simplicicornis (Banks) attacks buildings, shrubs, and trees.

II. Termite biology

A. Colony organization

All termites live in highly organized social communities. Individuals begin as transparent eggs and go through a larval stage before maturing into workers, soldiers, reproductives (future kings or queens), or secondary reproductives. Adults of these castes each have different physical features and behavioral roles

Workers are sterile, wingless, soft-bodied, and light in color. Their duties may include the following: caring for eggs and young, feeding and cleaning other colony members, foraging for food, and constructing and maintaining shelter tubes. Although workers are not found in drywood termite species, they generally represent the most numerous caste and are often the colony members seen in an infested sample. Because workers are the damaging wood-eaters, they represent strategic targets when defining control programs. Sometimes, workers become secondary reproductives which supplement the number of eggs laid by the queen. Soldiers have enlarged brownish heads and long mandibles (mouthparts). Their job is to defend the colony against predators, particularly ants.

Sexual adults (reproductives) are black or yellow-brown in color with two pairs of equally long wings. In contrast to winged termites, winged ants have wings of unequal length, bent not straight antennae, and hard bodies with thin waists and pointed abdomens. Only a few termite workers develop into sexual adults, and not many of these reproductives survive their short dispersal flight from the mother colony. Most are eaten by predators (other insects and birds) or suffer desiccation. Surviving males (kings) and females (queens) shed their wings and establish pairs, then excavate a cell in or near wood in the ground and mate. Most species in the United States lay less than one hundred eggs in the first year, but this number normally increases with the age of the colony. A five-to-six-year-old colony may have several thousand members, and produce winged reproductives yearly.

B. Food sources and the need for symbiotic protozoa

The principal food of termites is cellulose, a constituent of wood and other plant tissues. Qualifying foodstuffs include not only wooden building components but also utility poles, paper products, and fabrics derived from cottons and other plants. When searching for food, termites may also damage non-cellulose materials such as plastic. Foraging tunnels made in wood are called galleries. A preference for soft spring wood over harder summer wood often leaves the food source layer-like and hollow-sounding.

Subterranean termites and drywood termites both maintain symbiotic associations with gut protozoa. These protozoa, essential for digestion, are responsible for the initial enzymatic breakdown of cellulose in ingested material. Drywood termites excrete undigested lignin in the form of hard pellets which are stored in their galleries. (Lignin is the stiffening substance found in the secondary walls of plant cells.) Periodically, these six-sided pellets are pushed out through small "kick holes" made in the wood. In contrast, subterranean termites plaster their excretions on gallery walls. They also use their excrement to form delicate honey-comb structures within galleries, and to cement soil particles together when creating protective shelter tubes.

C. Importance of soil and moisture

Aside from cellulose, the presence of soil and moisture are, to varying degrees for each family, key elements in termite survival. Soil serves three main functions: it provides a source of moisture to prevent soft-bodied termites from drying out, it serves in protection against predators, and it is employed as a building material for construction of above-ground shelter tubes. Since some termites carry soil with them, termite presence can be accompanied by that of wood fungi and consequently, wood decay.

Drywood termites are least dependent on the soil and are able to build above-ground nests in sound dry wood. Dampwood termites however must nest in moist decaying wood, even though they can extend tunnels into drier parts of the wood. Subterranean termites require the greatest amount of moisture. They live in the soil and tunnel through it to reach wood located above ground. Sometimes this foraging behavior necessitates construction of protective shelter tubes. These passages reach from the soil to above-ground food source and reduce the risk of desiccation and attack by predators.

III. Termite detection

A. Introduction

Discovering damage to wood and wood products, and identifying the causative agent can be accomplished by the lay person. Findings can be confirmed by a professional from a local Cooperative Extension Service, college entomology department, natural history museum, or pest control company. When inspections are done by the homeowner, the first place to look for damaged wood members is where water collects. To distinguish termites damage from other types of wood damage the following should be kept in mind. Fungi are generally associated with wood that is discolored, shrunken, and weakened. Insects are associated with wood that has holes, tunnels, galleries, or chambers on or beneath the wood surface. Holes less than a half-inch in diameter signal the presence of wood-boring beetles; holes greater than a half-inch in diameter are indicative of carpenter bees. The presence of galleries or chambers that are easily penetrated with a screwdriver signify termites. The basic signs of subterranean termite presence are outlined below; most have already been mentioned.

B. Signs of termite presence

1. Gallery construction

There are various signs of subterranean termite activity. One is the presence of feeding tunnels or galleries within infested wood. Subterranean termite galleries run along the wood's grain and are marked with grayish specks of excrement and soil. These termites do not reduce wood to a powdery mass or push wood particles to the outside as other wood-boring insects do. Drywood termites cut clean galleries <u>against</u> the wood's grain. Fecal pellets, pushed outside, often collect in nearby piles. Because drywood termites usually damage wood less quickly than subterranean termites do, the structural weakening they cause is most likely to be seen in older buildings.

2. Shelter tube formation

Earthen shelter tubes, often seen extending over the surface of foundation walls, are another sign of an active subterranean termite colony, especially if they are quickly rebuilt when tampered with. Shelter tubes are characteristic of subterranean termites exclusively.

3. Nesting habits

Most subterranean termites found in the United States do not construct clearly defined nests. However, the Formosan termite (Coptotermes formosanus Shiraki) builds what is called a "carton nest". It is made of chewed wood, saliva, and feces, and serves to retain moisture as well as provide protection from predators. Carton nests permit above-ground colony establishment and become dry and hard when not occupied. Formosan termites are notably more aggressive tunnelers and consumers than species of Reticulitermes.

4. Presence of winged termites or shed wings

The presence of winged termites (reproductives) or shed wings, often near windows or lit areas, also indicate termite presence. Such evidence suggests that winged termites have either emerged within the building and have been unable to escape, or that they have been drawn to the lights of the house from outside.

5. Other

Aside from these rather obvious signs of subterranean termite activity, one can predict where an infestation is likely to be found if one reflects on basic termite biology. Since termites seek out cellulose products, soil, and moisture, they should be found in areas supporting such resources, for example, beneath buildings and decks, and around leaky pipes and wet wood.

IV. Monitoring

A. "Do-it-yourself"

It is believed by some researchers that annual monitoring is a very effective way to see and treat termite problems, and that it can essentially negate broad scale use of toxic pesticides. Monitoring entails careful inspection of the residence for conditions conducive to establishment of termite colonies. Inspections can be done by the owner, a professional, or both. Homeowners, when working alone, should first walk around the house and record its dimensions on grid paper. This sheet can be duplicated for note-taking during subsequent monitoring. Attention should be paid to conditions that attract termites such as chronically damp wood or soil (for subterranean termites), or dry caked areas of wood (for drywood termites); the signs listed above can serve as indicators of termite activity.

When monitoring, it is advisable to wear coveralls, a helmet, and gloves since many of the areas that should be checked are cramped and hard to reach. A flashlight, a screwdriver for probing, and a hammer for sounding are all helpful tools. A moisture meter with a range of 15-24 percent, a pencil, a clipboard, grid paper, and a measuring tape are also useful. A ladder may be required to reach roof and attic areas. Inserting a hacksaw under the sills or headers of earth-filled porches near crawl spaces can be used to detect deterioration (the blade should not go beyond the sill or header). Caulk can be brought along for quick seals.

These exterior sources of trouble should be carefully inspected: foundations, brick or stucco veneers, foundation air vents, plumbing areas, planters and trellises, and window and door casings. Indoors, inspection should center on areas that are stained or have mold growth, on sagging or buckling floors, and on attached rooms and garages. Simply put, any area prone to moisture retention, separation, or decay is a potential termite entry point.

B. Hire a professional

If a professional is chosen for the monitoring, the company should offer annual termite monitoring services for a fee separate from that of treatments. It is important to remember that most termite infestations are slow to cause damage and that a pest control company should not pressure a client into contracting for treatments. Paying a separate fee for monitoring may help ensure that the consultant offers an unbiased opinion of the situation. Clients can request to see samples of insects and decayed wood found during monitoring.

One advantage to having a professional do the monitoring is the use of dogs by pest control companies. These dogs (usually beagles) are specially trained to smell and hear wood-damaging insects. They are able to search where humans cannot gain access and can detect infestations missed by pest control operators. The dogs are insured for errors and results obtained with their help are admissable in court should any lawsuits arise. Although this type of inspection is somewhat more expensive than the regular kind, the cost is justified by increased efficiency. Unfortunately, this service is not widely available and it appears that consumers will have to encourage pest control companies to offer it.

When inspection results are in, homeowners can decided whether or not treatment is necessary. If it is, then the most effective but least-toxic procedure can be delineated. If a pest control operator is hired to do the work, he should be familiar with alternative treatments and be willing to implement them reliably and in close consultation with the client. When a least-toxic program is pursued, an educated consumer is key to obtaining satisfactory results.

V. Termite prevention

A. Introduction

Probably the most effective and least costly time to protect against subterranean termite damage is during the planning and construction of a building. Three main types of prevention may be considered: removal of wood debris and other food sources, reduction in available moisture, and elimination of soil-wood interfaces. Other, more direct methods of prevention will be considered later in our discussion.

B. Basic preventative measures

1. Food removal

Before construction begins, all roots, stumps, and wood and paper debris should be removed from the building site. Wooden spreader sticks and grade sticks should be removed before the concrete hardens. Form boards and scrap lumber need to be discarded before filling and back filling are done around completed foundations. Elimination of such items denies termites food sources and accessways to building members during and after construction.

2. Reduction in available moisture

Moisture sources used by termites include the water contained in unseasoned wood, rain and ground water, condensation, and water from plumbing leaks. Termites feed mostly on wood wetted by rain seepage, soil, or leaky pipes. Buildings should therefore be designed and constructed so as to permit rapid drainage of water, particularly from foundations and roofs.

On roofs for example, heat from the attic can melt snow lying above. The water then runs down the roof and freezes on the overhang which is cooler. Additional water collects behind this "ice dam" and soaks under the shingles, often resulting in damaged ceilings or walls. Such consequences can be prevented by increasing attic insulation and by inserting flashing to protect the area under the shingles.

Shingles often present another problem. In the past, they were placed without paper on narrow wooden strips which permitted both inward and outward drying after rains. Today, since shingles are usually laid directly on solid plywood, drying is restricted. Adding to potential water collection is the tendency for modern roofs to be of low pitch. This further slows drying and allows soggy organic matter to accumulate. Given these trends, treating shingles with a wood preservative appears to be the best preventative measure.

The outside finished grade at a building site should be equal to or below the level of soil beneath the structure. This stops water from becoming trapped under the structure and also exposes the foundation wall which facilitates inspection for termite activity. Gutters and downspouts attached to eaves also help move water away from a building. In certain instances, it may be necessary to install drainage tile around a building's foundation.

Ventilation openings, found in foundation walls beneath buildings with crawl spaces, need to be sufficiently large and properly distributed so as to prevent formation of dead air pockets. These pockets give rise to humid conditions favorable to termite infestations. Cross ventilation is best achieved when openings are within ten feet of the building's corners. Care must be taken so as not to obstruct ventilation openings with shrubbery and thereby prevent inspection.

3. Removal of soil-wood interfaces

a) Basements and other areas

Certain preventative measures should be taken to decrease the availability of soil-wood connections. The formation of physical barriers (e.g. increased distance between soil and desirable building parts) serves this purpose. Such barriers force subterranean termites to build shelter tubes which convey their presence. For example, siding should not extend more than two inches below the top of foundation walls, piers, or concrete caps, and should be six inches above the outside grade. An eighteen inch minimum clearance between the ground and the bottom of the floor joists should be allowed, and clearances for beams and girders should be twelve inches.

Porch supports should be separated by two inches from the building to prevent hidden entry, and wooden steps should rest on a concrete base six inches above the ground. Door frames and jambs should not extend through concrete floors, and window wells near the outside grade should be at least six inches below the nearest piece of wood. Wooden partitions, posts, and stair carriages in basements need to be installed after the concrete is poured and should not extend through the concrete. Wood used in basements should be pressure treated with a wood preservative.

Metal termite shields have been used as replacements for concrete caps usually placed atop masonry foundations. If correctly designed, installed, and maintained, a shield will force termites to create revealing tunnels around and over their bent-down edges. However, since these shields are often improperly used, they are not presently recommended for detection and prevention of termites.

b) Crawl spaces

In crawl spaces, all plumbing and electrical conduits must be kept off the ground, suspended from girders or floor joists but not supported by wood blocks (an easy area for termites to tube over). Generally, it has been advised to chemically treat the soil around basements and crawl spaces, and to fill gaps in foundation walls or concrete slabs if pipes penetrate these areas. Spaces under concrete porches, entrance platforms, and other raised units should not be filled with soil. Rather, they should be left open, with access doors for inspection. If soil-filling is necessary, it is sometimes advised to chemically treat the soil and keep it six inches from nearby wood sources. The most termite resistant type of foundation in buildings with crawl spaces is of poured concrete with reinforced piers to prevent large shrinkage or settlement cracks (a .03 inch space is enough for termite entry). The least resistant type of crawl space construction employs only pressure-treated piers.

c) Slab-on-ground foundations

Certain homes, with neither basements nor crawl spaces, have concrete slab-on-ground foundations. This type of construction is very prone to termite attack. Termites can reach the building by going over the edge of the slab, or by going through expansion joints, openings around plumbing, or cracks in the concrete. Infestations occurring under these circumstances are difficult to control and chemical treatment of the soil, before the concrete is poured, has been recommended to prevent attack. The best type of slab-on-ground construction is use of a "monolithic slab". In this case, the floor and footing are poured in one continuous operation, eliminating vulnerable joint areas.

The next-best type of slab-on-ground construction involves a "suspended slab". This slab extends across the top of the foundation and is constructed independently of it. It prevents hidden entry as long as the lower part of the slab is open to view. The least resistant type of slab-on-ground construction is the "floating slab" in which the slab rests on the foundation's ledge or is independent of it. In either case there is direct connection between the soil, expansion joints, and the foundation walls.

Other preventative measures include: inspection of all new wooden articles (e.g. furniture, picture frames, and crates) to avoid introduction of an infestation; caulking outside cracks and joints, and painting or varnishing all wooden surfaces; inspecting under siding, and between and under wood and fiberglass shingles; and timing building construction so that it does not coordinate with the swarming of termites.

VI. Termite control

A. Introduction

Control of each group of termites is facilitated by an understanding of the given family's physiology, behavior, and basic requirements. For example, the control of drywood and subterranean termites should be approached differently if one considers the amount of moisture each needs. Drywood termites require only the amount of moisture absorbed by air-dried wood whereas subterranean termites require more than that amount. Treatments for drywood and subterranean termites could therefore focus on, respectively, wood pretreatment and chemical barriers in the soil. Generally, termite control indoors involves eliminating conditions that favor the formation of termite colonies in the soil and that permit passage to wood within a building. Indoor control relies on inspection, sanitation, and chemical control. To simplify discussion of the available methods of termite control, I have broadly classified treatments as "chemical", "biological", and "physical". (This scheme is followed throughout subsequent sections.)

B. Chemical methods of termite control

1. Introduction

Traditionally, termite control operations have stressed the application of insecticides. These substances (e.g. the fumigant methyl bromide and the liquid chlordane) are among the most toxic approaches available. Increased concern regarding associated health and environmental hazards, highly-publicized accidents by poorly-trained pest control operators, new government restrictions, and the increased availability of alternative control techniques have set the stage for re-thinking traditional methods and developing newer, less toxic approaches. However, situations remain in which the use of insecticides to control termites is still warranted. In such cases, there are two ways to lessen potential health hazards. One is to restrict application of a traditional insecticide, the other is to select a non-traditional insecticide.

2. Chemical control of subterranean termites: formation of a soil barrier

a) Barrier concept

Subterranean termites are best controlled by the preventative measures outlined in the previous section. However, complete control by these methods is difficult and sometimes expensive. It is commonly believed that the most effective and least costly program combines good construction practices with creation of a chemical barrier between the soil in which the subterranean termites live and the desirable cellulose sources above. Termites living in the soil under and around a building meet with the barrier when they are foraging. While some soil chemicals kill termites, most serve as repellents that force the insects to travel in a different direction.

b) Criteria a soil insecticide must meet

Before a chemical is selected for screening as a soil insecticide, it must exhibit relatively low mammalian toxicity. That is, greater than 500 mg/kg oral LD_{50}, greater than 2000 mg/kg dermal LD_{50}, and greater than 2 mg/l inhalation LD_{50}. The chemical must also have low water solubility (less than 50 ppm), and exhibit stability on the soil. Other considerations include the chemical's effect on non-target soil insects and its marketing potential.

c) Screening

Screening potential soil insecticides in the laboratory serves two purposes. First, it saves time and money which would otherwise be spent on extensive field testing of ineffective or short-lived chemicals. Second, screening isolates chemicals which are persistent, that is, are toxic or repellent to termites for a long period of time. Apparently persistent chemicals are further tested in laboratory and field studies. The chemicals are screened against R. virginicus (Banks) and C. formosanus Shiraki.

d) Activity

The activity of selected chemicals is determined by restricting worker termites to a thin layer of treated soil in a Petri dish. Changes in behavior and physiology are noted over an eight hour period. If the specimens become moribund or die when exposed to a wide range of concentrations (0-1,000 ppm wt/wt), the chemical is selected for follow-up tests. Treated soil is stored and bioassayed at six month intervals to verify persistence of termicidal activity. If effectiveness is maintained while on the soil, the chemical is tested in the field.

e) Repellency

Chemicals which are repellent but not toxic to subterranean termites are also studied. In tests concerning these chemicals, termites are allowed to "choose" between treated and untreated soil. If a statistically significant number of termites remain on the untreated soil, the chemical is considered to be repellent. If it is repellent over a wide range of concentrations, the treated soil is stored and bioassayed at six month intervals. Ideally, a chemical should be both repellent, and toxic on contact (even brief contact with some chemicals can result in delayed mortality).

f) Stomach poisons / protozoacides

Chemicals which are neither toxic nor repellent in eight hour bioassays on soil are retested using powdered cellulose to see if the chemical can act as a stomach poison. For two weeks termites are exposed to dyed and treated cellulose. Their physical condition and the quantity of dye in their gut is monitored daily. After this time, hindgut protozoa are counted. If there is a significant drop in protozoan number, the chemical is subsequently evaluated as a protozoacide in "choice" and "no-choice" tests. If termites feed on the treated cellulose and if the chemical is slow-acting, it is considered for the "bait block" method of control (to be discussed later, in connection with insect growth regulators).

g) Field testing

Field evaluation is the final and most time consuming phase of testing prior to registration of the chemical with the United States Environmental Protection Agency. A minimum of five years efficacy data from four nationwide locations is required. These evaluations are performed by the United States Department of Agriculture Forest Service at sites throughout the mainland, and on Sand Island of the Midway Atoll and in Panama. These sites were chosen to represent semiarid, temperate, subtropical, and tropical climates.

(1) "Ground board"

Two field tests are used to assess a termiticide's effectiveness: the "ground board" and the "concrete slab". In the ground board method a seventeen square inch area of soil is cleared and then soaked with a known concentration and volume of a chemical solution. A sapwood pine board is centered atop the treated area and weighed down. Termites must penetrate the insecticidal barrier to reach the desired wood. If termites fail to attack the board, the barrier is considered effective.

(2) "Concrete slab"

The concrete slab method simulates conditions associated with slab-on-ground types of construction. The soil is treated as in the ground-board tests, then covered with a polyethylene vapor barrier. A plastic pipe four inches in diameter, placed in the center of the soil, serves as an inspection port. The vapor barrier around the pipe is covered with a one inch layer of concrete. This test was developed in response to the introduction of organophosphate and carbamate insecticides which are subject to degradation by sunlight and leaching in exposed conditions, but are effective under and around buildings. With both these methods, treatments are replicated a number of times and the boards are examined annually. Once a treatment board is attacked, it is discounted and no longer examined.

h) Chlorinated hydrocarbons

Subterranean termites have been successfully controlled for more than thirty years by chlorinated hydrocarbons. Chlordane, heptachlor, and a chlordane-heptachlor mixture were frequently used termiticide formulations. In tests conducted by the Forestry Sciences Laboratory in Gulfport, Mississippi, the following chlorinated hydrocarbons were found 100 percent effective for the stated duration: 1.0 percent chlordane, thirty years; 0.5 percent heptachlor, twenty-six years; and 0.5 percent aldrin and dieldrin, twenty-nine years.

While these chemicals are very effective, they are also capable of accumulating in the food chain, and their persistence makes them potential soil contaminants in residential areas which have been converted for other (recreational) purposes. Further, their use has created the illusion that regular monitoring and habitat modification are unnecessary. It has been shown that termites can reappear even in treated areas (the recurrence rate is however lower than that associated with buildings which have neither been treated nor monitored).

If expectations concerning these chemicals could be lowered, say to an 80-100 percent level of effectiveness for a seven to ten year period, then chlordane for example could be considered effective at concentrations as low as 0.125 percent in the United States (provided the proper volume of treating solution is applied). Risks may also be minimized by confining the application of these chemicals to areas removed from the resident, such as under concrete slabs or beneath soil barriers which would prevent vapors from entering the home through heat ducts or other openings.

i) Other chemicals

Other termiticides, currently used and registered with the EPA, include: chlorpyrifos, cypermethrin, fenvalerate, isofenphos, and permethrin. All can be bought from certified pesticide applicators and used with their supervision. Chlorpyrifos can be purchased and used by homeowners only in some states. These chemical solutions are least expensive and easiest to prepare when purchased as liquid concentrates formulated according to the percent of toxicant contained. Each concentrate contains an emulsifier to make it mixable with water, and each must be diluted before use. Recommended final dilution concentrations are as follows: 1.0 percent chlorpyrifos, 0.25 - 0.5 percent cypermethrin, 0.5 - 1.0 percent fenvalerate, 0.75 percent isofenphos, and 0.5 -1.0 percent permethrin. It may be viewed as a small concession that one commonly used chlorpyrifos formulation Dursban[R], an organophosphate, has a shorter life-span (eleven to fourteen years) than the chlorinated hydrocarbons. But, its LD_{50} value of 135 mg/kg falls between that of chlordane (LD_{50} = 250 mg/kg) and aldrin (LD_{50} = 38 mg/kg). Note that the lower the LD_{50} value, the greater the material's toxicity.

j) Application methods

Chemicals may be applied with a power sprayer or tank-type garden sprayer using low pressure to prevent misting. The type of soil involved and the amount of moisture it contains both affect the rate of solution acceptance. Excessively wet soil leads to runoff and prevents proper penetration of the chemical; frozen or dry soil causes puddling and prevents even distribution of the chemical. Damp soil offers the greatest acceptance. It is important to note that treated soil must be protected from mechanical disturbance since even slight losses in barrier continuity increase the risk of termite entry. For example, treatment of fill under slabs is less than two inches deep, with most of the chemical concentrated in the top three-fourths of an inch. It is easy to see how intolerable even slight disturbances in such areas are. Final treatment on the outside of foundation walls should be done after all grading and disruption are over. Treated soil can also be washed away by rain, so it may be necessary to cover areas if concrete is not poured soon after soil treatment. Most soil insecticides stay put once they are dry and are most often insoluble in water, so leaching is usually not a concern. But, water supplies can be contaminated if the insecticide is applied to soil containing layers of gravel or to soil which tends to crack in droughts.

If a chemical barrier is not established prior to pouring the concrete in a slab-on-ground foundation, and if an infestation is later discovered, a chemical barrier can still be created. A series of half-inch holes drilled vertically into the slab about eighteen inches apart are each injected with the chosen chemical in such a way that overlap provides adequate coverage of the soil. Holes may also be drilled horizontally through the exterior foundation to the soil just beneath the slab and the chemical injected through these ports.

3. Chemical control of drywood termites

a) Pretreatment of wood

There are three commonly accepted methods of drywood termite control: pretreatment of wood, fumigation, and "in-place" treatment. Pretreatment of wood entails treating lumber with a preservative, either by a pressure or non-pressure process, before the wood is used. Some common preservatives are creosote and creosote solution, oil-borne preservatives (pentachlorophenol), and water-borne preservatives (inorganic and metallic salts). The pressure process provides long-term protection against drywood termites as well as subterranean termites and wood decay fungi. The degree of protection gained by the use of chemically treated woods depends on the kind of preservative used, the degree of penetration, and retention of the chemical in the wood. Preservatives must be applied at standard retention rates and satisfactory penetration attained. Maximum protection is achieved through pressure impregnation using an approved chemical.

Pretreated wood can be considered part of a "least-toxic" program because it can be used in a limited area during construction and as a replacement for damaged or hard-to-monitor wood in susceptible areas. Of the materials used to pretreat wood, those containing copper are the least toxic. Since pentachlorophenol, arsenicals, and creosote products pose health hazards, are on the EPA's restricted materials list, and will eventually be unavailable without a permit, new preservatives will be sought.

Marketed preservatives of relatively low toxicity have the following as active ingredients: copper naphthenate, copper-8-quinolinolate, zinc napthenate, polyphase (3-iodo-2-propynl-butyl carbamate), TBTO (bis-tributyl-tin-oxide), and TBTO / polyphase. For soaking the wood, follow the label instructions. (Soaking is preferred over brushing since it increases absorption of the preservative.) When treating the wood yourself, it is advisable to wear a respirator with an activated charcoal filter, and to use washable or disposable gloves. To further decrease the amount of preservative you apply, the chemical can be used just on the most vulnerable part of the lumber which is the end, taking care that the treatment is done after the item is trimmed. A mask should be worn when sawing treated wood to prevent inhalation of the sawdust.

Compared to the above preservatives, a recipe given by the USDA Forest Service is even less toxic, but still provides a high level of protection for treated woods. The active ingredient is copper-8 quinolinolate, the only wood preservative approved by the Food and Drug Administration for use on tables with which food or humans make contact. The active ingredient is combined with the Forest Product Laboratory's water-repellent formula in these proportions: 12 ounces of boiled linseed oil, 1 ounce of melted paraffin wax, 105 ounces of solvent (paint thinner), and 9.5 ounces copper-8 (10 percent concentrate) to 0.75 percent copper-8.

b) Fumigation

Although fumigation can kill all termites existing in a structure, it is an expensive procedure and requires that the area be evacuated for a day or two until the poisonous vapors dissipate. The infested building is draped with an airtight covering of nylon or polyvinyl chloride and the fumigant is introduced in several areas under the cover. Sulfuryl chloride (Vikane[R]), at 1 pound per 1000 cubic feet of space and at a temperature of seventy degrees Fahrenheit or above, can be used if the building is kept covered for twenty-four hours. Methyl bromide is effective at 2-3 pounds per 1000 cubic feet. Aside from fumigation being expensive and inconvenient, the chemicals are highly toxic and do not provide permanent protection. Once the fumigant has dispersed reinfestations can occur, although fumigation should not be needed for another six to eight years. Some pest control operators use vaults to fumigate small infested articles.

c) "In-place" treatment

"In-place" or spot treatments refer to application of insecticides only to areas where termites have been detected or where monitoring is difficult. This technique stands in sharp contrast to traditional recommendations of applying long-lasting insecticides to every potential infestation site. Least-toxic spot treatments are considered most effective when combined with habitat modification, biological controls, and/or physical controls.

Localized infestations can be controlled by the "drill and treat" method, a process which involves drilling small holes into infested wood and injecting toxic chemicals. Chemicals which are commonly used include Perma-Dust PT[R] 240, PT[R] 270 Dursban[R], PT[R] 250 Baygon[R], and PT[R] 2230 Tri-Die. But, since this method protects only select areas and because thorough application can be difficult, termites are not always eliminated. Heavy-bodied oil emulsions containing pentachlorophenol and heptachlor have also been used to treat wood surfaces.

A less toxic alternative to these spot treatments is offered by the use of desiccating dusts. These dusts can be applied during construction to prevent infestations or after fumigation to prevent reinfestations. A desiccating dust can be abrasive or sorptive in nature. That is, it can either abrade or absorb the waxy layer on an insect's outer coat, causing dehydration and eventually death. Diatomaceous earth, a powder made from naturally-occurring deposits of fossilized diatoms, functions both to abrade and to absorb. It is found as an inert in a number of products and works against many pests. It is safe enough to be added to grain in storage to eliminate pests, and can be used as an additive in animal foods for control of intestinal parasitic worms in cows, horses, and dogs. (The form of diatomaceous earth discussed here is not the glassified sort used for swimming pool filters.)

Silica dust is sorptive in nature. It comes in two forms, amorphous precipitated silica (not to be confused with the crystalline form that causes silicosis in industry workers) and silica aerogel. Both prevent drywood termite attack. Silica gels are highly effective due to their large specific surface areas, adequate pore diameter, and low sorptivity for water. Dri-die 67[R] has been used for over twenty years and has a low mammalian toxicity (LD_{50} > 3,160 mg/kg). Laboratory feeding tests report no toxic effects in test animals and no pathology observed in laboratory rats feed up to 25,000 ppm for twenty-eight days. Drione[R] appears to be even safer with an LD_{50} value of over 8,000 mg/kg. Drione[R] contains 40 percent amorphous silica aerogel, 1 percent pyrethrins (a plant derivative added for quick kill or knock-down), and 49 percent petroleum distillate (carrier). It also contains the synergist piperonyl butoxide which allows the product to supply 60 percent more ammonium fluosilicate than Dri-die[R]. Ammonium fluorosilicate enhances the product's effectiveness by conferring a positive electrostatic charge to the silica gel particles which enables them to adhere better to the target insect. The charge dissipates after a few months and effectiveness of the dust is reduced to that of an unfluorinated silica gel. Because fluorine is an environmental contaminant, there is controversy over use of the synergist.

Silica gels are useful in confined areas such as attics for drywood termites, in sewers and wall voids for cockroaches, and in the house and yard for young fleas. Generally, silica aerogel is used in attics at the rate of 1 pound per 1,000 square feet to prevent winged drywood termites that enter via crawl spaces from boring into the wood. While actively crawling about, the termites pick up the dust and die in as little as two hours. It has been noted that even small amounts of silica aerogel dusted onto wood blocks will prevent feeding by exposed termites and consequently limit their survival to about two weeks. (Termites in non-treated controls were meanwhile feeding vigorously.) Silica aerogels are inorganic and not subject to decomposition, and they offer protection for the life of the treated building. However, they are toxic to fish and should not be allowed to contaminate natural bodies of water or home aquaria. When using these and other, even non-toxic dusts, it is advisable to protect yourself with goggles and a dust mask. Signs posted in the treated area are helpful to future residents and inspectors.

4. Wood extractives

a) Resistant woods and their resistant properties

Work done at the Southern Forest Experiment Station in Gulfport, Mississippi has involved the use of wood extractives as termiticides. It is known that certain woods are more resistant to termite attack than others and that resistant species include bald cypress, eastern red cedar, chestnut, Arizona cypress, black locust, redwood, osage orange, black walnut, and Pacific yew. Resistant properties result from chemical constituents of the wood which are distasteful, repellent, or toxic to termites.

b) Isolation of resistant species

A study conducted by Carter and Dell (1981), aimed at isolating species of resistant American wood, determined the survival and feeding responses of R. flavipes (Kollar) on selected species of hardwoods. Heartwood blocks were cut from forty North American hardwood species which represented twenty families. Blocks from each board were tested using workers taken from three out of nine available colonies (this minimized the effects of biological variation of the termites on the test results). After eight weeks of exposure to the blocks, surviving termites were counted. The test blocks were subsequently weighed and the amount of wood eaten was estimated. Boards were then placed in one of four categories: "S" (susceptible, 60-79 percent termite survival), "MS" (moderately susceptible, 30-59 percent termite survival), "MA" (moderately antitermitic, 1-29 percent termite survival), and "A" (antitermitic, 0 percent termite survival). The "A" group contained these species: Northern catalpa, camphor tree, American holly, yellow poplar, osage orange, white and red mulberry, sycamore, post oak, sassafras, and winged and cedar elm.

c) Repellent and distasteful woods; wood extractives as protozoacides

Resistant woods need not be toxic, and may instead be repellent or distasteful. Under force feeding or "no-choice" tests with these types of woods, termites die from starvation. A non-toxic material can also act by eliminating symbiotic protozoa. Laboratory testing of protozoacides is preferred over field evaluation since the former takes less time, provides more uniform testing conditions, and allows for a more quantitative assessment of results. Overall, laboratory tests involving wood extractives are believed to predict reasonably well the results of long-term field tests with the same or a closely related termite species.

d) Extraction of resistance components

Once a resistant species is identified, solvents such as methanol, pentane, and acetone are used to extract the components of the wood which confer resistance. Various methods are employed to isolate and identify the active components, although it has sometimes proven difficult to isolate a pure sample of the "resistance factor". Extracts are tested on filter pads for antitermitic activity and compound identification is then pursued using chromatographic and spectrophotometric methods. Studies are also done to determine just how the antitermitic substance works (for example, whether or not it targets gut protozoa).

e) Uses for antitermitic compounds derived from wood

In the United States, the use of resistant woods in construction has been almost totally replaced by chemical treatment of wood. Nevertheless, investigation of the propeties of resistant woods is still worthwhile. It is projected that antitermitic wood extractives, in crude form or as a constituent thereof, might be useful as wood preservatives for non-resistant woods, as bait termiticides, or for use in soil barrier treatments. Analogs for such purposes may also be developed.

The potential of wood extractives has been illustrated experimentally by Carter and Beal (1982). Five inch long and one-half inch square sapwood sticks were treated with extracts from five woods (catalpa, holly, melaleuca, post oak, and yellow poplar) which had proven effective as wood preservatives in preliminary field tests. The treated sticks were inserted in holes cut in untreated pine sapwood stakes (ten stakes per extract) and the stakes driven into the ground. After one year, only two of the fifty sticks showed damage that was greater than surface nibbling. In contrast, 60 percent of the controls were attacked.

The experiment focused on commercially important species of American hardwoods and noted the variable nature of their antitermitic properties. Variation has been found to exist between trees of the same species and even within a single tree in which heartwood is resistant but sapwood is not (e.g. yellow poplars). Further, the antitermitic component in the heartwood may be unevenly distributed. Accurate determination of species resistance can be made only after a large number of trees have been sampled. In certain instances, an active extractive component may be volatile or susceptible to chemical changes when exposed to air. The estimated degree of resistance in woods with these compounds therefore depends not only on the tested termites, test conditions, and length of test period but also on the length of time the wood has been cut prior to testing.

5. The bait block method and the use of insect growth regulators

a) Bait block method as a viable alternative

One difficulty in killing termites, opposed to other pests, is that their nests are often hard to locate. Even if their nests are located and the queen is killed, supplementary reproductives can take over and allow the colony to persist. Control through the use of bait blocks has basically been viewed as supplemental to more traditional approaches and has been restricted to areas where termite pressure is low. However, since the residues of soil termiticides are increasingly being viewed as health and environmental hazards, the bait block technique may offer a more viable alternative than previously expected.

b) Goal; advantages; baits; toxicants

Unlike the barrier method of control which aims at excluding or repelling termites from certain areas, the bait block method aims at suppressing or eliminating colonies from a given area. Aside from the directness of its goal, the bait block method has other advantages. First, it involves only a small quantity of slow-acting toxicant. Second, it is not associated with any actual or perceived environmental hazard. And third, it does not pose the long-term threat associated with persistent chemicals. Also, the bait block method can be employed at various stages in the construction of a building. For example, treated bait blocks can be placed around susceptible pine stakes in a grid like form prior to construction to suppress the existing termite population and lessen the termite hazard on a construction site. Attempts to re-establish a feeding network (destroyed by construction) would be thwarted by the bait blocks. Perimeter baiting around a plot of susceptible stakes could be used to intercept invading termites.

The use of baits to encourage contact with an insecticide is a technique well-suited to social insects like termites, given their foraging, food exchange, and grooming habits. Toxicants used on the bait blocks include stomach poisons, protozoacides, insect growth regulators (juvenile hormones), and combinations of these. Some believe that use of slow-acting toxicants is the only feasible way to eliminate colonies of *C. formosanus* which may support up to ten million individuals and maintain foraging galleries as long as one hundred meters.

c) Mechanism

In theory, the bait block technique works as follows. Foraging workers from a colony locate and feed selectively on a toxic bait block. They then return to the colony and distribute the toxicant to other colony members via trophallaxis (food exchange). Through toxicant transfer, the colony is eventually decimated. Field study involving *C. formosanus* Shiraki (Su et al 1984) has shown that individuals of this species select their feeding sites at random. This "random selection" of feeding sites implies that, if given enough time, all foragers from a colony will eventually encounter a control agent that has been introduced just at a single site, with the end result being colony elimination. Because the bait block method relies on preference of the toxic block over any other available food source, the blocks are often decayed by the brown-rot fungus *Gloeophyllum trabeum*. This fungus does not act as an attractant, but it does cause workers to exhibit an arrest response (i.e. they stop, and remain on the treated wood).

For the toxicant to perform adequately, it must be lethal, possess minimal antifeedant properties (so as not to discourage feeding on the toxic block), and act slowly. The latter characteristic gives poisoned foragers time to leave the bait block site and return to the nest, still able to poison their nestmates. If foragers died at the bait block, not only would spreading of the toxicant be prevented, but, as part of normal termite behavior, contaminated individuals would be walled off and the site subsequently avoided.

d) Testing

Initial testing of bait block toxicants involves a no-choice test in which a series of cups containing dyed treated cellulose and a layer of lab stone are placed within a larger covered container. Each cup has a small hole in the bottom which allows water to be drawn up from a moist cotton pad below. Twenty-five *R. virginicus* or *C. formosanus* workers are introduced into each cup. Three replicates are done for the controls and each treatment concentration (12.5 - 5000 ppm). Test units are examined for two weeks, with daily observations of behavior and physical responses. Sometimes, at the end of the first and second weeks, the number of symbiotic protozoa in the termite hindgut are estimated for several concentrations. If the toxicant used is an insect growth regulator, a longer period may be needed to observe associated effects. Dead termites are removed at each examination to minimize fungal and bacterial contamination. Potential bait toxicants usually begin to adversely affect termites after several days, and 100 percent mortality often occurs by the end of the second week.

Promising compounds are then used in choice tests in which termites are permitted to feed on either treated or untreated cellulose. A plastic nest unit is partially filled with a sand-vermiculite-water mixture and two pieces of untreated pine blocks are placed inside. The nest unit is connected to a smaller foraging chamber by a glass or plastic tube. In the foraging chamber is a block of fungus-decayed sweet-gum wood (Liquidambar styraciflua L.) vacuum impregnated with the chemical being tested (or the appropriate solvent if it is a control). Blocks are placed in the foraging chamber twenty-four to forty-eight hours after approximately one thousand termites are introduced. The blocks are then covered with a thin layer of the sand-vermiculite-water mixture and a bit of distilled water is added. When the units are dismantled, the termites are counted according to caste. Each bait block is cleaned of debris and dried, and its oven-dried weight compared with the original dried weight.

Only chemical concentrations that cause significant mortality over several weeks without exhibiting strong antifeedant properties are considered for field tests. As long as workers are present in the appropriate numbers, feeding should continue. However, assessment of feeding habits when insect growth regulators are used must be made carefully since effectiveness of the toxicant is not strictly correlated with decrease in weight of the toxic block. Field testing entails placing bait blocks next to susceptible pine stakes in chosen test plots and evaluating the damage done to the susceptible stakes over time.

e) Juvenile hormones

The role of juvenile hormones in caste differentiation and regulation, and the development of their structural analogs has presented an interesting opportunity for termite control. It is known that soldier differentiation in subterranean termite colonies depends on the titer of juvenile hormone present at certain times in the molting cycle of nymphs and larvae. Further, it is believed that juvenile hormone titer and the resulting number of soldiers are controlled by pheromones produced either by reproductives or by soldiers. Pheromones produced by reproductives are believed to stimulate soldier production, whereas those produced by soldiers are believed to inhibit soldier production.

f) Juvenile hormone analogs and their effects

Juvenile hormone analogs (JHA's) or insect growth regulators (IGR's) are synthetic versions of natural juvenile hormones. They can regulate the growth and reproduction of insects and are useful in insect control programs because they prevent proper mating and hence reproduction. Assuming no immigration occurs, population number can be visibly reduced.

Since mammals have different chemical growth regulators and develop in a different manner, adverse effects on humans through use of IGR's to control pests is unlikely. The biological specificity and low mammalian toxicity of IGR's make them promising components for control programs. The IGR methoprene for example has an LD_{50} of over 34,000 mg/kg and has been found to be effective for five to six years.

However, IGR's do not provide immediate kill. If quick results are desired, insect growth regulators must be considered as a component within a more extensive control program. The use of IGR's is further limited by the migratory habits and life cycles of the insect being treated. Probably the greatest concern regarding IGR's is that they will be used in mixtures with conventional insecticides -- an approach which will inhibit the switch to preventative procedures and least-toxic methods of pest control. To lessen the existing potential for development of resistance to these IGR's, it is urged that their use be restricted to enclosed settings, where migration of insects is eliminated.

JHA's have a number of effects on termites. Most are associated with the assumption of soldier or soldier-like characteristics. Specifically, JHA's cause workers to develop soldier-like characteristics and cause undifferentiated nymphs to become normal presoldiers and "intercastes" (nymph-soldiers morphologically distinct from normal presoldiers). Loss of microbial symbionts, feeding inhibition, failure of colony establishment by dealate pairs, and overt toxicity are other consequences. These effects have been observed in a number of species but responses depend on the chemical and its concentration, the termite species, and the substrate. The most dramatic consequence seems to be production of superfluous presoldiers and soldiers. This occurrence causes a skewing of caste proportions and consequently creates an energy deficit within the colony. That is, as the number of dependent colony members rises, fewer and fewer workers are available to care for them. Further reduction in the number of available workers is caused by new foragers returning to the toxic bait block. This "snowball" effect can lead to starvation of an entire colony.

g) Examples of juvenile hormone analogs and their consequences

Until 1983, studies primarily involved the JHA's methoprene and hydroprene. At low concentrations (0.016 - 0.063 ppm on filter pads), methoprene was found to cause the production of an excess number of soldiers in laboratory colonies of R. flavipes and R. virginicus (Banks). It also caused the loss of symbiotic protozoa. At higher concentrations (0.125 - 2.5 ppm), methoprene was found to be toxic. Methoprene has also been implicated as a factor in egg mortality and female infertility. In an experiment done by Howard (1980), unflown alates from four colonies of R. flavipes were collected and segregated by sex. Groups of each sex were held separately by colony on filter paper in a darkened incubator at about twenty-five degrees Celsius for less than twenty-four hours. They were then exposed to direct sunlight which induced dealation. Experimental units contained two strips of weathered pine and a moistened sand-vermiculite matrix. The wood had been soaked with 0, 31, or 62 ppm methoprene in acetone and air-dried in a fume hood. One pair of dealates from the same colony were placed in each unit. The units were sealed with paraffin and placed in an incubator at about twenty-five degrees Celsius. Units were checked daily for one week, and two or three times weekly thereafter for four months. Data included the number of eggs produced, the number of eggs hatched, and the number and stage of larvae present. Five replicates per source colony were used for each treatment concentration.

Within forty-eight hours, all the pairs began construction of their nuptial cells, most near to or on top of the wood. Egg laying started around the eighth day (except in two methoprene-treated units in which no eggs were ever produced). The average length of time to deposition of the first egg and the average total number of eggs produced did not differ for the three treatments. But, the average amount of time required for hatching and for appearance of second- and third-stage larvae were significantly greater in units containing the methoprene-treated wood than in controls. Also, fewer eggs were hatched in the treated units. It is unclear whether these effects are due to methoprene acting as an ovicide or from its induction of sterility in the females. Those methoprene-exposed eggs which did hatch developed normally, although effects may have been delayed. It is known that colonies founded by alates of R. flavipes in wood impregnated with methoprene are less successful than colonies founded in untreated wood. The conclusion that can be drawn from this study is that JHA's can be used as a form of "birth control" against infestations of R. flavipes (Kollar).

The JHA's 2-[p-(m-Fluorophenoxy)phenoxy]ethyl ethylcarbamate (Ro 16-1295) and fenoxycarb do not exhibit the antifeedant properties that JHA's like kinoprene, triprene, hydroprene, and methoprene do. Jones (1984) has shown that fenoxycarb and Ro 16-1295 cause intercaste production in C. formosanus Shiraki and R. virginicus (Banks). In the latter, the number of intercastes was over 50 percent at four weeks, and survival was significantly reduced by six weeks. Larvae and workers had differentiated into soldier-like workers, and nymphs had become intercastes with uneven pigmentation, misshapen wings and abnormal mouthparts. Mandible length and head shape also varied. At six weeks the number of intercastes in C. formosanus also reached about 50 percent, however, significant mortality was not achieved. It was found that differences in food substrate altered the response of this species; intercaste development occurred on treated wood blocks but not on treated cellulose.

6. Antibiotics used to eliminate symbiotic protozoa

The necessity of symbiotic protozoa for cellulose digestion in certain termites is well known. But, this relationship has not often been exploited as a control mechanism. Experiments have shown that elimination of just one species of protozoa from C. formosanus Shiraki or R. flavipes (Kollar) prevents lipid synthesis and termite survival. Aside from wood extractives and methoprene, other chemicals such as antibiotics also cause the loss of symbiotic protozoa. Maudlin and Rich (1980) attempted to determine whether or not antibiotics could be used in bait blocks. Atabrine, chloroquine phosphate, and chlortetracycline (CTC, aureomycin) were chosen for the studies since they are known to cause the loss of protozoa in R. flavipes workers.

The antibiotics were each vacuum impregnated into "attractive" wood blocks or absorbent paper pads at three concentrations (0.1 percent, 1.0 percent, and 3.0 percent) in deionized water. In choice tests, untreated wood blocks were readily eaten whereas feeding was inhibited on blocks treated with atabrine and chloroquine phosphate. An inverse relationship was found to exist between the amount of applied chemical and the degree of feeding. Because ingestion was slight and protozoa numbers barely affected, these two antibiotics were eliminated from testing. Their anti-feedant properties would make them unsuitable for use in bait blocks.

However, termites readily fed on blocks treated with CTC even if untreated blocks were available. After two or three weeks, protozoan numbers were quite reduced in group given 4-5 mg CTC. It was also found that higher concentrations did not eliminate protozoa any faster or better than lower concentrations; the 3.0 percent concentration was less effective than lower concentrations in choice situations. Also, the number of Dinennympha sp. per termite was reduced after two or three weeks at concentrations of 1 and 3 percent CTC. But, T. agilis and Spirotrichonympha sp. persisted after three weeks. The indication is that after three weeks, protozoan elimination results in termite starvation. Controls persisted long after this time.

In no-choice tests using 1.0 or 3.0 percent CTC and wood blocks or filter pads, protozoa were eliminated after three weeks. As in choice tests, protozoan number decreased rapidly as CTC concentration increased but a 1.0 percent solution appeared to be adequate. Since untreated blocks present in the choice test did not prevent the loss of protozoa, it is unlikely that forced feeding on treated blocks in the no-choice test caused semi-starvation. Effects observed in no-choice tests paralleled effects known to occur when termites are given methoprene, namely, that once the protozoa are eliminated, termites are unable to digest cellulose and starve to death within two to three weeks. Although survival on treated blocks was comparable to that of controls, termites lost more weight when on the treated blocks. The conclusion that can be drawn from this study is that CTC is a potential bait block chemical, and that it is more effective at lower (1.0 percent solution) concentrations than higher concentrations. If CTC is employed as a control, adjustments must be made to account for dilution as it is passed between termites by trophallaxis.

7. Liquid nitrogen as a control for drywood termites

Another alternative to conventional chemical treatment for drywood termites was recently investigated by Charles Forbes and Walter Ebeling (1986). It involves the use of liquid nitrogen which, when applied to infested wood, essentially freezes infesting termites to death. This method is advantageous for at least two reasons. The first being that liquid nitrogen is inexpensive and environmentally benign. The second being that liquid nitrogen, when changed to gas upon release from the applicator, is able to reach areas in buildings that are inaccessible by conventional means (e.g. "drill and treat" method). Although investigation has targeted the drywood termite, many other insects of colonial or resticted habits are also potential victims. Insects unlikely to escape this treatment include carpenter ants, pharaoh ants, fire ants, plaster beetles, psocids, bees, and possibly fleas. Other pests (e.g. powderpost beetles) living in cabinets, panels, or floors, can be confined by a cold-resisting, insulating tarp.

Initial testing was aimed at measuring temperatures reached in the wooden parts of a mock-up wall, the voids of which had been injected with liquid nitrogen. Successful results pointed to the feasiblity of attaining lethal temperatures to control drywood termites (Incisitermes minor). Subsequent experiments concentrated on developing equipment and methods of application which could be confidently employed by pest control operators.

To determine the temperature at which termites could be killed in a reasonable amount of time, specimens were placed in the freezer compartment of a refrigerator. Mortality figures were derived for drywood termite nymphs and alates, and also adult Tribolium confusum beetles. Groups of twenty insects representing each species or stage were placed in a Petri dish on a piece of filter paper. The temperature was measured using an Atkin thermocouple digital thermometer. The freezer was set to approach its lowest point (-4 degrees Fahrenheit). At -1.94 to 0.572 degrees Fahrenheit, all insects were killed within five minutes.

Testing continued with a modified mock-up wall which had features characteristic of residential buildings. Uninsulated areas were covered on both sides by drywall, but insulated areas were covered by drywall on the interior and siding on the exterior. A window was placed in the insulated area since frames and sills are common areas of infestation. Temperatures were again monitored with the thermocouple, but a switching device was added to permit collection of temperature data from up to twelve locations in the wall. Testing determined rates of application and temperature required in the wall voids to ensure lethal temperatures in adjoining wood members, and also the length of time needed to maintain the flow of nitrogen to attain the desired temperature.

Twenty drywood termite nymphs or alates, or adult Tribolium confusum beetles were placed in thin pyrex glass tubes and confined to the distal portion by a wooden rod inserted into the tube. The tube was plugged with cork and inserted into a hole drilled into the center of a 2-by-4 inch stud. The lethal temperature therefore had to penetrate the wood and the glass tube before reaching the insects. (The part of the tube extending to the outside was covered with insulation.) Temperature readings were taken from a hole drilled into the center of the same stud just above the insects (temperature of the insects was assumed to be the same).

The part of the stud last to respond in both insulated and non-insulated areas of the wall achieved the lethal temperature in an hour and fifteen minutes or less. To reach this temperature inside the stud, wall void temperatures did not have to fall below -112 degrees Fahrenheit. However, since some wooden components were large or in an effort to hasten the process, temperatures were sometimes dropped as low as -292 degrees Fahrenheit. Several tests showed that when temperatures in the stud reached -4 degrees Fahrenheit, the insects were dead. Due to the low temperatures in the wall voids, temperatures in the studs continued to drop. The temperatures could remain at -4 degrees Fahrenheit for over two hours even though this temperature can kill the subjects in less than five minutes. Deliberate overkill ensured complete elimination in all parts of the treated areas. Further, it was found that covering the wall sections with an insulating material increased efficiency of the process and required use of less nitrogen over a shorter treatment period. Insulating mats also prevented frost from forming on the outer surface of the wall.

Field testing was carried out at two locations. The first involved a drywood termite infestation in the outer wall of an apartment building. Nitrogen was conducted from an outlet valve near the building to holes drilled to the voids from the outside. Thermocouple sensors were placed on the inside of these holes (areas expected to be most delayed in achieving -4 degrees Fahrenheit). Insulating mats were not used.

Another field test was conducted involving a wall and post of a condominium porch. Part of the post was within the wall and extended above it. The area of the post near the wall was flanked by two studs. Mats were laid against the treated part of the wall and also wrapped around the exposed section of the post. For low temperatures to reach the post's center, they had to penetrate the studs and then the post. In thirty-two minutes, the bottom of the post reached -20 degrees Fahrenheit, but -101.7 degrees Fahrenheit was reached at the upper site (near the input jet) in the same amount of time. The exposed section of the post was treated by injecting nitrogen under the mat. The lower end reached -15.5 degrees Fahrenheit in one hour, but by then it was -97.2 degrees Fahrenheit in the upper site. When -4 degrees Farenheit was reached in the lower site in the part of the post within the wall, the temperature stayed below -3 degrees Fahrenheit for sixty-five minutes. The corresponding site in the exposed post was still below -4 degrees Fahrenheit thirty minutes after the nitrogen injection.

Research continues on improved application and equipment mechanisms, including development of an automated metering and timing device and an application nozzel for floors and walls. The survival of other pests (household fleas, C.formosanus, and fire ants) exposed to liquid nitrogen is also being evaluated. Precautionary measures needed for this technique include shutting off and draining water pipes, and shutting off gas pipes near the treatment site. The effects on non-treated areas and the risks associated with the method's application are somewhat unclear. At this point, the application of liquid nitrogen may require an hour or more at each infestation site. This makes the procedure expensive compared to other methods, but with integration into the pest control industry the cost will presumably drop. Equipment and technical training should be available to pest control operators in the near future.

C. Biological control of termites

1. Termites and fungi

A number of fungi and termites use cellulosic materials as food and compete for the same nutrients. It has been shown that wood decayed by some fungi elicits a positive feeding response, whereas other fungus-decayed wood is toxic or repellent. One goal of research has been to develop new approaches to termite control with these relationships in mind. As stated earlier, the success of bait blocks depends on the positive feeding response elicited by termites such as R. flavipes (Kollar) to wood decayed by the brown-rot fungus Gloeophyllum trabeum. The fungus does not act as an "attractant" rather, when it is found by the foraging workers, it is preferred over available non-decayed wood. Preferrence for this type of decayed wood, after it is treated with a toxicant, is a critical factor in determining the success of the bait block technique. As of 1978, Amburgey (1979) cited no studies involving development of a control technique based on negative behavioral responses elicited by termites to non-pathogenic fungi.

2. Termite predators

Several animals feed on termites under various circumstances, but ants are their primary predator in the United States. It has been shown that a disturbed termite colony is quickly invaded and attacked if ants are nearby. Yet, sometimes, a termite colony (e.g. Reticulitermes spp.) and a fire ant colony (Solenopsis spp.) are found coexisting in dead logs. The use of predators for termite control, at the present, has not been thoroughly explored. But it is known that Argentine ants (Iridomyrex humilis), common in California and the southern areas of the United States, can kill a large number of termites overnight. Subterranean termite shelter tubes normally provide protection from these invaders as long as they remain intact. It is when swarming termites have just emerged from the soil, just landed at a new colony site, or during the early stages of colony establishment that they are most vulnerable to ant attack. Insecticides regularly applied at foundations of buildings against predaceous ants negate a rather effective and natural form of termite control.

3. Termite parasites

a) Nematodes vs termites

Some groups of nematodes (round worms) are specific to insects and do not harm plants, animals, or microbes. Spear™, a mixture of predaceous nematodes, is a commercial product that is applied to infested soil or wood as a water solution in the same way that conventional termiticides are. The nematodes can, over the span of a few inches, seek out the termites, enter their bodies, and kill them. Because termites feed on their dead or dying nestmates and also share food and feces, parasitic nematodes can quickly circulate throughout a termite colony and destroy part or all of it.

The entomogenous nematode <u>Steinernema feltiae</u> Filipjev (<u>Neoplectana carpocapsae</u> Weiser) has been investigated as a control for <u>R. tibialis</u> (Banks) in both laboratory and field situations. This species of termite is widespread from the deserts of California to Illinois, and up to Montana. It is similar in habit to <u>R. hesperus</u> Banks and to <u>R. flavipes</u> (Kollar) and is found in dry areas. It is responsible for less damage than other species simply because fewer opportunities to attack buildings exist in its normal habitat. <u>R. tibialis</u> feeds on native and structural wood and is often found in herbivore dung. Laboratory trials suggest that the following species are also susceptible to this nematode: <u>C. formosanus</u> Shiraki, <u>Nasutitermes costalis</u> Holmgien, <u>Zootermopsis</u> sp., and other <u>Reticulitermes</u> species.

Researchers at the University of Hawaii, working with laboratory termite colonies, have found that elimination of colonies is possible with nematodes. But, they have also found that infected individuals, when introduced into a colony, are quickly walled off and cease to be effective parasite carriers. Epsky and Capinera (1988) determined the laboratory efficacy of <u>S. feltiae</u> against <u>R. tibialis</u> by setting baited traps in areas where the termites foraged. Each trap consisted of a wood-strip frame and a cloth floor plus two pieces of moistened laminated cardboard as bait. Twenty-five out of the twenty-nine traps set were attacked. Whether or not termites attacking the traps came from the same colony was not determined, but the choice of well-spaced colonies insured that many separate colonies were evaluated.

In laboratory tests, field-collected termites were placed in Petri dishes with tight-fitting lids, each containing a section of 4 percent agar with a piece of sweetgum wood (Liquidambar sp.). LD_{50} estimates were made using Petri dishes containing two pieces of filter paper and ten termites. Doses of 0, 100, 3,200, 10,000, and 100,000 nematodes along with 1 ml formalin (0.1 percent) were applied to each dish. Five replicates per concentration were done, using termites from different traps in each one. Termite mortality was recorded at thirty-six, sixty, and eighty-four hours after inoculation. Testing confirmed the susceptibility of R. tibialis to S. feltiae and showed that termites exposed to the second dose were all dead within eighty-four hours.

Additional trials utilized a substrate of wood chips in 4 percent agar to assay termite mortality in choice tests and to determine termite avoidance of nematodes. The experimental setup included three plastic cups connected by plastic straws. In the first trial, two hundred nematodes in 1 ml formalin were added to the right or left cup in each behavior arena. The other cup was supplied with 0.1 ml formalin but no parasites. Ten workers were then placed in the center cup and allowed to choose between the nematode-filled and nematode-free cups. In the second choice trial, zero and ten thousand nematodes (each in 0.5 ml formalin) were used, and ten termites were added. The number of termites and their location in each of the arenas were recorded for one week. Avoidance was said to be indicated by feeding in the nematode-free cups. Little mortality occurred in choice tests with ten nematodes per termite (trial one), but 100 percent mortality occurred in choice tests when five hundred nematodes were given per termite (trial two) within three days. It was also noted that termites fed little in the paper-Petri dish assay as opposed to the agar substrate assays in which they actively tunneled and chewed the agar, increasing the chance of infection.

In the no-choice test, substrate was added to all three cups and twenty workers were added to the middle cup. After one week, termite location was recorded. Either zero or two thousand nematodes in 0.25 ml formalin were added to the cup where most of the nematodes were. Movement out of the original location (indication of avoidance behavior) and the number of termites surviving after one week were recorded for each of the twenty-three behavior arenas. In the arenas with one hundred nematodes per termite 58.2 percent mortality was found. Other studies achieved 98 percent mortality with two hundred nematodes per termite and 100 percent mortality if 133 nematodes were given per termite. Termites did not avoid nematode-infested areas in either choice or no-choice trials.

In field tests, nematodes were applied at a rate of $1x10^7$ per square meter to soil below termite traps and termites were counted at three subsequent samplings. Results showed that the baits could only be protected for two to three weeks at the applied nematode rate. Untreated traps generally had numerous entrance holes and a network of tunnels. Many termites were found under the traps. In contrast, termites attacking treated traps entered at the corner or went around the frame and attacked the top. The undersides had few holes and hardly any termites were found underneath these traps.

This experiment confirmed the termite's susceptibility to the nematode but also illustrated the fact that termites avoid areas with large numbers of nematodes or try to exploit small gaps in nematode-covered areas to reach a food source. The potential for reinvasion by termites suggests that it may be more effective to treat the whole colony rather than just the feeding site and hence eliminate the need for frequent nematode application.

Colony extermination has been obtained in studies on the live-wood tea termite Glyptotermes dilatatus with Heterorhabditis sp. These termites behave like wood-boring beetles and are able to live inside wood with little or no connection to the ground. Although these subjects are very different from subterranean termites, a chain of infection similar to that seen in the study could provide a way to eliminate subterranean termites. Research regarding other strains of S. feltiae (or other nematodes) and application methods required for long-term protection need to be pursued.

b) Controversy

Olkowski's update (1985) indicates that the use of nematodes in commercial applications has met with mixed success. Stan Post and Bob Drucker head the company N-Viro which distributes SAF-T-SHIELD™, a product containing the parasitic nematode N. carpocapsae, strain forty-two. The parasites are sold in units of four million at a cost of thirty-nine to fifty dollars. Post has treated four thousand stuctures since the spring of 1984 and believes that the nematodes are helpful in controlling termites in residential areas. The company's success rate is estimated to be 80 percent (not far from the 92 percent maximum given for chlordane). The estimate is based on the number of re-treatments and reports from other pest control buyers. It is expected that increased operator training will raise the effectiveness level. The dosage relationship between different soils and the quantity of nematodes must still be determined, as must the routineness of the treatment.

Another pest control operator says he regularly injects nematodes under concrete-slab foundations to treat existing termites and finds the technique 95-100 percent effective. Still another company reports that they are achieving 50 percent effectiveness with initial treatments. The indication seems to be that follow-ups are necessary, particularly when preventative modifications have not been made. Initial treatment results are expected to improve once a way to help the nematodes withstand drying has been developed.

Ironically, it is precisely this short-lived characteristic that makes nematodes such an appealing prospect for termite control. Unlike conventional long-lived insecticides, nematodes can survive for only two years, depending on the availability of moisture. While this ensures that no harmful residues remain in treated areas, it also makes monitoring more crucial, especially where re-treatment is concerned.

Some negative conclusions on nematode use have been drawn by the media in response to research results obtained by Raymond Beal at the Wood Products Insect Laboratory of the U.S. Forest Service in Gulfport, Mississippi. Field tests, performed in much the same way as for conventional insecticides, were used to evaluate nematode effectiveness against termites. Field plots were covered with eight to forty thousand nematodes per square foot. A pine board was then placed over treated areas, covered with a black polyethylene vapor barrier, and held in place with a concrete slab. After one and two months exposure, Beal calculated the percentage of damage.

George Poinar, an insect pathologist at the University of California at Berkley, was asked to comment on the media's conclusions and cited several aspects of the study which he found problematic. One is that the field site contained what could be considered an unlimited supply of termites. As the nematodes killed termites, other termites moved in and continued to feed until the nematodes were used up. (The nematodes were basically "outnumbered".) Poinar does not consider the field site typical of most residential infestations and thinks that the results of the study are somewhat of a testament to the usefulness of nematodes. He also points out that the strain of nematodes used in the Beal study was not the one (strain twenty) that is commercially distributed. Poinar concludes that the Beal study should not be considered indicative of the potential use of nematodes and that negative publicity, the large investments made in conventional methods, and a general unwillingness to change will delay appropriate investigations. It should be noted that Beal has stated that his work was preliminary and that conclusions from the study should be drawn carefully. Fortunately, some pest control operators have forged ahead. Obviously, communication between pest control operators and researchers could help in the development of suitable uses for nematodes and ease the transition of this and other control techniques into industry.

4. Termite pathogens

Research has involved pathogenic fungi and bacteria as possible methods of control. Several patents are involved with pathogenic bacteria, but their practical value is questionable.

D. Physical methods of termite control

1. Use of extreme heat

The susceptibility of insects to high temperatures has also been exploited as a means of control. Using thermostatically-controlled temperature cabinets, Charles F. Forbes and Walter Ebeling (1987) have determined the amount of time required to achieve 100 percent mortality of adult male German cockroaches Blatella germanica, adult flour beetles Tribolium confusum, nymphs of the western drywood termite Incisitermes spp., and adult Argentine ants Iridiomyrmex humilis, at 115, 120, 125, and 130 degrees Fahrenheit. The least amount of time required for 100 percent mortality was found when the temperature was increased from 115 to 120 degrees Fahrenheit.

Another experiment by these researchers determined the amount of time needed to reach 115, 120, and 130 degrees Fahrenheit in a block of Douglas fir (3.25-by-1.50 inches in cross-section and 4 inches in length). Temperatures were determined via thermocouple sensors set within the center of the wood block. Tests were also done using a larger block at 160 degrees Fahrenheit. Drywood termites nymphs were placed in the centers of the blocks in an effort to simulate treatment of structural infestations. The emphasis was on attaining lethal temperatures within a practical time span.

A small mock up house was used to see how long it would take for lethal temperatures to be reached inside various wooden members. The house included components found in conventional residential construction such as 2-by-4 inch studs, 4-by-12 inch headers, and 6-by-12 inch beams. A crawl space, attic, ceiling joists, and wall voids with and without insulation were also included. Air from an electrically-driven blower was passed through a gas-filled heater and into the house through an eighteen inch insulated flexible metal duct. Heated air was drawn out through a similar duct at the opposite end of the house and recycled back into the blower. Heating efficiency was increased by covering the roof with tar paper and wrapping the entire house with a black plastic tarp. The latter ensured that lethal temperatures were maintained in the outer surfaces of the house. Temperatures were monitored in twelve locations per treatment via thermocouples. Temperature curves were determined for various locations in the house, and the room temperture was not raised above 180 degrees Fahrenheit.

In another test, the room temperature was not raised above 160 degrees Fahrenheit and a quarter-inch tunnel was drilled into the center of a 2-by-4 inch ceiling joist. Drywood termite nymphs and flour beetles were placed in the bottom and the tunnel packed with fiberglass insulation. It was found that a half-hour at 120 degrees Fahrenheit was sufficient to kill the insects. Similarly, two hundred German cockroach nymphs, twenty adult flour beetles, and numerous cat flea (Ctencephalides felis) larvae, pupae, pre-adults, and adults were confined in the plastic containers and placed in the house. All were dead after thirty minutes at 120 degrees Fahrenheit. Compared to free-living house-hold pest, wood-inhabiting pests are somewhat protected in their chambers and require more time to be killed by higher temperatures.

A smaller, lighter heating device was used in field tests. Five treatments of drywood termites and one of carpenter ants were performed. In the second story of a two story condominium, two bedroom-living room units with termite-infested ceiling beams were treated. A bathroom through which alates had entered was also treated. All three rooms were accessible by balconies and the heater was carried to each of these sites. Propane gas was conducted to the heater by a hose from a tank situated on the ground below. Access to the bathroom was attained by means of a duct pulled in from one of the bedrooms. A hole was drilled to the center of a ceiling beam in each room and a sensor was inserted before the hole was packed with insulation. In the first treated room, 120 degrees Fahrenheit was reached in fifty-three minutes in the ceiling beam.

In another case, a 4-by-6 inch termite-infested beam in a second story balcony was treated. A plastic tarp was placed over the balcony and loosely held down with duct tape. A flexible duct brought heat from the ground-level heater to the balcony. The temperature under the tarp rose from seventy-four degrees Fahrenheit to 140 degrees Fahrenheit in six minutes, with the beam center temperature reaching 120 degrees Fahrenheit in seventy-six minutes.

One treatment involved carpenter ants (Camponotus clarithorax) which had infested a kitchen-breakfast-utility room area for ten years. At this site, the duct was directed for hot air discharge along the floor, thereby avoiding the stratification of heat that had been noted in earlier experiments. A sensor was placed in the center of a 2-by-4 inch stud under the sink cabinet. To reach the stud center, heat had to penetrate 3/8 inch plywood and then the stud itself. In three hours 120 degrees Fahrenheit was achieved. No workers or alates have since been found in this treated area.

In all the heat treatments done by the reasearchers for drywood termites, a good deal of "overkill" was aimed at presuming that areas difficult to reach would be adequately exposed. All visible fecal pellets had been removed prior to the treatments and no new pellets have been seen since. There was no damage detected to usual house furnishings or their contents, except for candles which melted when temperatures at certain times rose to 130 degrees Fahrenheit. Thin plastic containers and similar items were found to become somewhat distorted. It was also found that heat applied to only one side of a door caused the door to warp (i.e. a concave surface resulted on the heat-exposed side). Normal shape was regained upon cooling.

A full-scale treatment was done on a two bedroom house infested with powderpost termites (Cryptotermes brevis). The house was covered with a tarp as done for fumigations, and the heat discharged from the machine through the front door. The attic was not insulated and the access hole to the attic from the hallway was left open. Temperatures were again monitoered via sensors inserted into various wood members. Attic and living space temperatures were also monitored. Lethal temperatures of 125 degrees Fahrenheit or more were reached in two hours in all the areas where the sensors had been placed.

2. Sand barriers for control of subterranean termites

The use of sand or crushed volcanic cinders as a barrier to R. hesperus was proposed by Ebeling and Pence in 1957. At that time, it was observed that termites construct tunnels at the rate of about an inch per hour. They do this by pushing their head forward in the sand and by using their head and mandibles to press the sand particles to either side of the tunnel. Smaller particles are taken in their buccal cavities and placed along tunnel walls to form a smooth and tightly sealed surface. A spot of fecal "cement" is put down before particles are set. Termites use their broad hypopharynx (tongue) for pushing particles and for spreading sand, earth, and fecal material. To build above-ground shelter tubes, termites carry small sand and soil particles in their buccal cavities and grasp larger ones in their mandibles. Their mandibles have a span of only 0.5 mm, but by grasping an edge termites can move particles up to 1 mm in size.

Recently, experimentation has been pursued and a patent applied for by Ebeling and Forbes (1988). This seemingly simplistic type of control targets termite tunneling and tube-building behavior by substituting a penetrable medium with an impenetrable one in areas through which termites are likely to be moving. An indirect advantage is that the sand helps to absorb dampness in termite-prone areas.

The 1957 study showed, and recent studies confirm, that fine dry sand cannot support subterranean termite galleries. Specifically, it has been shown that R. hesperus nymphs are unable to penetrate a layer of dry or moist sand consisting of particles ranging in size from 2.5 to 1.6 mm (ten to sixteen mesh). (Note: high mesh number means mesh openings are smaller and that fewer large particles are accepted.) The smallest particles in this mixture are too large for the termites to move aside and the largest ones cannot be crawled around. The mixture is still effective even if larger particles (six to sixteen mesh) are added, as long as the barrier is tamped to remove penetrable spaces. Nymphs are able to penetrate dry or moist grit, or particles 3 mm in diameter. They can also tunnel through fine moist sand.

To successfully implement this sort of control, sand must be of the required range, be used industrially, and be available commercially. The sixteen or twelve (mesh) sand used in sand blasting is acceptable and inexpensive (about four dollars for a hundred pound sack). A sample of twelve grit sand has the following composition: 71.4 percent ten to sixteen mesh, 9.5 percent larger than ten mesh, and 18.5 percent smaller than sixteen mesh.

At the USDA Southern Forest Experiment Station, Susan Jones performed various tests with the aggressive tunneler C. formosanus. Using groups of about 750 workers and soldiers, Jones found that the termites could penetrate a three-fourths inch layer of dry twelve grit in six days; in three days if it was moistened. Dry sixteen grit was penetrated in twenty-four hours. These experiments indicated that particles smaller than 16 mesh should be removed from a mixture unless their percent in the composition is small and the barrier is tamped to prevent penetration.

Sand barriers can be applied in the crawl spaces inside or outside a foundation's perimeter. Since laboratory tests proved that a sand-concrete barrier can resist violent shaking, these barriers could be used in crawl space construction to seal earth-filled porches, patios, and steps from the foundation, and could also be used to repair similar barrier interfaces which have been disrupted. A six to sixteen mesh sand used in these cases would have to be tamped to ensure removal of penetrable spaces. In slab-on-ground construction, the sand would have to be applied before the concrete is poured and may need to include a layer of gravel to weigh down the sand or cinder barrier.

In a recent field test, a crawl space under the residence of a chemically-sensitive person was provided with a sand barrier. The infestation had originated on the outside and had reached wood via tubes stretching from below the ground through loose stucco, to the sill, and then to cripples, joists, flooring, and studs. A concrete termite barrier six inches wide and eight inches deep had been installed when the house was built. It encircled the foundation but had been separated from it in certain areas due to foundation movement. This barrier was removed, and enough concrete was poured into the resultant trench to hold an eight inch wide strip of metal flashing three inches from the foundation. Twelve grit sand was poured between the flashing and the foundation to a depth of seven inches. Pouring the sand to within a half inch of the top of the flashing was expected to prevent roots that penetrated the concrete from going any further in providing termite access. Salt (also a termite barrier) was sprinkled in the lower part of the sand barrier to combat potential breaks between the concrete and the foundation. The refilled trench was covered with a cap of concrete. Results have been successful. Movement into the substucture has ceased and no new infestations have been found.

Generally, the formation of a sand barrier outside a foundation is a simpler process and suitable for both crawl space and slab-on-ground types of construction. In one treated area, a compressor (able to hold 250 pounds of sand) was connected to a fifty foot long tube one inch in diameter, and used to blow sand into a crawl space. Three hundred pounds of sand were blown from the hose at the rate of one cubic foot per five minutes to create a barrier one inch deep and covering an area twenty inches wide by twenty-four feet long. The sand was tamped with a brick to increase efficacy of the barrier. The whole process took about seventeen minutes.

3. Digging up subterranean termites

One type of physical control that can be exerted on subterranean termites is simply digging up small colonies. Even if all the termites are not removed in this process, digging breaks apart the nest and exposes remaining termites to attack by natural predators such as ants. Regular monitoring of these sites is recommended, as more digging out may be necessary. Shelter tubes can be broken easily or removed entirely to destroy the connection between soil and wood and further increase the probability of natural-enemy attack.

4. Termite control by electromagnetic devices

Electromagnetic devices were once sold as preventative and remedial controls for termites. However, tests conducted by the Forestry Sciences Laboratory in Gulfport, Mississippi showed that they were ineffective. The EPA issued a "stop sale" on the devices since manufacturer claims were not substantiated. Three different devices were tested and field tests with subterranean termites exposed to the mechanisms for six months showed no significant change in tubing behavior or in frequency of attack. In lab tests with drywood termites, no significant differences were found in mortality, amount of wood consumed, or increase in termite biomass after three months exposure.

5. Electrogun™

A new approach to elimination of drywood termites is use of the Electrogun™ The device is an AC pulsing generator that operates on a low current (90 watts), high voltage (90,000 volts), and high frequency (100 kHz). It aims at killing the insects in their galleries. The unit is safe for the operator to use and emits no harmful radiation (e.g. microwaves, x-rays, ultraviolet rays). The inventor of the device, Dr. L.G. Lawrence, made use of the fact that drywood termites frequently create galleries just below the surface of the wood. Access to the termites can also be gained through their "kick holes". Holes can also be drilled directly in the wood or a nail inserted to carry the current inside. Studies have shown that the current recommended can travel down half an inch and kill termites existing there.

The "Extermax System" (i.e. the name of the process using the gun) was tested by Dr. Walter Ebeling. Two hours post-treatment, moribund termites were dissected to determine the condition of their symbiotic protozoa. All protozoa in treated termites were found to be dead, while those in untreated controls were still alive. Five days later, treated termites also died. This lag time, between treatment and death, is characteristic of the technique but the exact cause of termite death is not clear. It is probably connected with the loss of symbiotic protozoa.

Dr. Ebeling has observed the technique performed and states that the technician moves a probe rapidly over the infested area, stopping at galleries near the surface when the current's sound and appearance dictate it. From treated points, the current can flow eighteen inches, but probes cannot be pushed too far into the kick holes because the current will carbonize a path directly to the electrode, diverting it from the termite gallery.

Of the thirty-five Electrogun™-treated infestations followed by Dr. Ebeling, only three required follow-up treatment. In a questionnaire, eight out of nine operators said that they received fewer call-backs with this treatment than with the "drill-and-treat" method using conventional insecticides. One operator has found that with increased operator experience, call-back number has dropped. (One call-back was traced to aluminum-backed insulation that had interfered with the process.) Another operator says he has completed over $400,000 in business with the gun and offers a two year unconditional guarantee. The potential, he believes, is limited only by operator expertise. The Electrogun™ is distributed nation-wide and training is provided by the distributors. Research has been underway to adapt the tool to control of ground-dwelling insects such as subterranean termites and fire ants, but devices for this purpose were not on the market as of 1984.

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ANTS

I. Carpenter ants

A. Identification of problem

1. Introduction

There are five hundred species of carpenter ants (genus Camponotus) but only nine species are common in the United States. Secondary data derived from Cooperative Extension Service (C.E.S.) entomologists in several northeastern states indicate that carpenter ants are displacing subterranean termites as a primary concern of the general public. Fowler (1983) reached this conclusion assuming that the number of inquiries received by the C.E.S. was a function of the sighting incidence by the general public.

New Jersey C.E.S. data on structural pests shows that, in terms of total number of queries, carpenter ants, subterranean termites, wasps, and other ants all ranked higher than cockroaches (the most prevalent structural pest). This seems to point to a bias on the public's part towards concern over wood-damaging social insects versus more common pests such as cockroaches. The switch in queries began around 1960 and can be partially attributed to changes in weather, settlement patterns, and human awareness. Suburbanization increased the risk of structural pest attack in homes, but widespread and effective use of chlordane as a soil termiticide decreased the rate of subterranean termite infestations in relation to that of carpenter ants. This combination of events has apparently heightened the public's concern regarding potential carpenter ant problems.

2. Carpenter ants: in their natural environment and as pests

In their natural habitat, carpenter ants live in logs, stumps, and hollow trees and act as decomposers of decaying wood. They become a problem to humans when they enter wooden buildings and cause structural damage. Although long-standing infestations may require extensive repairs, minor repairs (if any at all) are most frequently necessary. Carpenter ants are important pests in the Northwest and the Northeast, and it has been estimated that several million dollars are spent yearly, particularly by the urban public, on control measures. Although worker ants will bite if provoked, it is their rather large size that seems to be of greatest annoyance. Once established indoors, carpenter ants behave like other house-invading ants in their search for food.

B. Carpenter ant biology

1. Colony organization

Carpenter ants, like termites, are colonial insects which mine in wood. Ant eggs hatch into white, soft-bodied, helpless larvae which pass through a number of growth stages prior to pupation and adulthood. Most larvae develop into workers (foragers) which support the queen and developing young. Adults are most often black, but they may be reddish-brown or yellow in color. There are three adult castes: worker, winged male, and winged female.

Workers vary in size from 5/16 to 7/16 of an inch, and are divided into two groups -- majors and minors. Majors are sexually-underdeveloped females which guard the nest and forage for food, transferring it to the smaller workers (minors). Minors expand the nest and care for the young.

Winged males (kings) develop from unfertilized eggs and are about 7/16 of an inch in size. Winged females (queens) develop from fertilized eggs laid by mated queens and are 3/4 of an inch long. Between spring and mid-summer, winged reproductives emerge from the mother colony to mate. Males die soon thereafter, but females shed their wings and establish new nest sites. Each queen excavates a small cavity in wood, seals herself in, and lays fifteen to twenty eggs. She feeds her young with mouth fluids derived from stored fat and metabolic conversion nutrients of her wing muscles. The first workers produced by the queen are small since they were nourished by her reserves, but when they mature they are responsible for tending to the next brood and expanding the nest. This allows the queen to devote all her energies to egg-laying. Although in most species there is only one queen per colony, each queen is able to lay thousands of eggs over what can be a fifteen year life span.

2. Nesting habits

Colonies reach a peak population size in three to six years, with worker number about three thousand. At that time winged reproductives are produced and new colonies set up, either by a single fertilized female or by movement of colony members through "budding". In the latter process, scouts establish small satellite colonies in firewood, lumber, and wood debris in or near buildings. Budding is considered the main mechanism behind house invasion. In a study conducted in urban areas of New Jersey, carpenter ants were seen in 75 percent of the 306 shade trees examined. Each colony kept their brood in one tree, but it was found that a number of auxiliary sites, joined by underground tunnels, existed in other trees.

It is possible that destruction of forested areas may cause the ants to seek out nearby buildings. Carpenter ants attack both hard and soft wood, often selecting out partially-decayed areas. It has been found that black carpenter ants cannot inhabit wood with a moisture content level below 15 percent, although colonies can be established in wall voids or cavities within a structure and sometimes even in the open. Nests usually start out in damp, somewhat decayed wood but later expand into dry wood. They need not be located inside an infested structure, and may instead be found in a hollow tree or stump located adjacent to the house, with ants entering the building through openings in the foundation. Colony members hibernate in the winter, unless the nest is in a warm part of the building. It is possible for all or part of a colony to move to a new site.

3. Food sources

"Honeydew" from aphids, leaf-hoppers, mealybugs, scales and white-flies is the primary food of carpenter ants. They also eat dead insects, plant and fruit juices, sweets, meat, grease, and fat. Workers can exist for six months without food and if under stress the queen and a few workers can persist through cannibalism.

C. Carpenter ant detection

1. Distinguishing from termites

Because correct identification of invading insects is directly related to the effectiveness of control measures, differences between swarming termites and carpenter ants should again be noted. Regarding morphology, carpenter ants have narrow waists and "elbowed" antennae, whereas termites have broad waists and slightly concave antennae. Behaviorally, carpenter ants use wood to construct their nests and to reach water and foodstuffs, but they do not eat the wood like termites do. Wingless adult carpenter ants can be found foraging for sweets or protein inside the house, their presence most noted in kitchens and other areas providing food and water between the hours of 11 and 2 pm. In contrast, termites need not leave the wood that they infest since it provides most of their resources.

2. Appearance of infested wood

Carpenter ant nests within a structure may be marked by slit like entrances or "windows" covered with a clear material made by the ants. Existing cracks and crevices can also be used as entranceways. Generally, wood shavings and frass (insect feces) will be seen just beneath an entrance. This "sawdust" may also be seen sifting from cracks in siding, behind moldings, in basements, and under porches. If the infestation is an active one, the shavings will be in the form of chips, the frass will be dark and square-ended, and there may be parts of or whole dead ants present in the debris. Carpenter ant tunnels are characteristically cut against the grain of the wood and are smoothly polished and free of wood shavings, soil, and fecal pellets. Invading ants make a rustling noise in the walls (this increases if you knock on the wall because the ants are sensitive to vibrations).

3. Professional inspections

As stated in the section on termite detection, beagle dogs are being used during professional inspections. It is possible that these dogs could also be trained to locate carpenter ant infestations. The expectation is that they would significantly improve the reliability of inspections and that this would lower the number of fumigations and facilitate spot treatment procedures.

D. Carpenter ant prevention
1. Introduction

Once it has been decided that treatment for the ants is required, a qualified person can be enlisted to follow the most effective, least-toxic route. Again, an educated consumer is a vital factor in the success of the chosen program. Monitoring before and after treatments is also critical since it measures the effectiveness of the control procedure. Because termites and carpenter ants are similar structural pests, recommended preventative and direct control measures are nearly identical under a least-toxic management program. To avoid repetition, I have simply highlighted certain aspects of the techniques previously discussed under termites.

2. Removal of attractive conditions

The first and most important step in prevention is to remove the conditions which are causing wood to become and remain damp; the construction practices previously outlined do a great deal in eliminating and preventing water retention around the home. Nonetheless, areas wetted by poor ventilation, leaky roofs, or roof gutter overflow are typical places to check for carpenter ants. Commonly tunneled wood includes porch pillars and supporting timbers, sills, girders, joists, studs, and window and door casings. Damaged wood should be replaced or repaired, and suspected wood should be probed with a screw driver or ice pick to see if it gives way under pressure. If ants appear, the nest has probably been located. Another way to prevent infestation is to remove firewood, stumps, and waste wood from around the home. Trees should be pruned so that they do not touch the building and provide an easy accessway for invading ants.

E. Carpenter ant control
1. Chemical control of carpenter ants
a. Conventional insecticides

Partial control of carpenter ants can be achieved through application of ant-roach aerosols or the residual insecticide malathion to areas encountered by the ants. The central factor in elimination of carpenter ant infestations aside from location of the nest and destruction of the colony, is elimination of the queen. Unfortunately, chemical controls are often used as a substitute for needed structural change and habitat modification; economic concerns are most often stated as the reason for a traditional approach.

b. Desiccating dusts

As with termites, desiccating dusts can be a major component of carpenter ant prevention. Both diatomaceous earth and silica gels are used, but boric acid dust is also effective. Boric acid is derived from borax and is non-volatile once in place. (That is, it does not enter the air and present a respiratory hazard.) It is applied as a light film which adheres to insects and is ingested by them during grooming. Boric acid dusts are most effective when kept dry, and can last for the life of the building in which it is applied. The best formulations include the following: an electrical charge to increase adherence to the target, an anti-caking compound, and blue coloring and a bitter taste to prevent ingestion by humans and pets. Boric acid dusts are manufactured primarily for use against cockroaches and a more detailed treatment is given in that section.

Special application tools are needed for applying this chemical in wall voids. Even small amounts of boric acid are poisonous if eaten by children or pets, so excess should be kept in sealed out-of-reach containers. During application, the material should not be inhaled or allowed to enter the eyes, and treated areas should be posted to prevent accidents. Baits and broadcast liquid formulations of carbamates and organophosphates insecticides are also available for the control of carpenter ants. If a choice exists between the two, baits are better since there is less exposure to the material.

2. Biological control of carpenter ants

Researchers at the Bio-Integral Research Center (editors of Common Sense Pest Control Quarterly and The IPM Practitioner) have found, in a pilot field test, that nematodes are effective at eliminating carpenter ant colonies. Although the technique needs to be perfected, it is predicted that nematodes can be used effectively against this insect, without presenting a hazard to resident of the structure. The researchers advise mixing a few teaspoonsful of the nematodes with a protein substance such as tuna fish or pet food, and placing the mixture where the ants will find it. Pre-baiting (i.e. without the nematodes) will establish how attractive the chosen bait is and will prevent wasting the nematodes. Sugary substances can also be used as baits but it is more likely that nematodes carried by a proteinaceous bait will reach the developing larvae and reproductives.

3. Physical control of carpenter ants

a. Electrogun™

The Electrogun™, as described under the discussion for physical control of termites, is also a useful tool for the control of carpenter ants.

b. Removal of nest, damaged wood, and strays

It is crucial to find where the nest is, then to remove damaged wood, the nest, and any strays. It is also important to remember that these ants sometimes nest in wall voids rather than the wood itself, and that a discovered nest may not be the primary one. If the ants in one area are eliminated, and the access points caulked, then it is probable that the infestation has been eliminated, at least in that area. When handling small infestations, a large sponge, saturated with a sugar solution can act as a trap. Once the ants have collected in the trap, they can be killed by sinking the sponge in a bucket of soapy water.

II. Other pestiferous ants

A. Identification of Problem

1. Introduction

Ants are numerically the most abundant social insects. There are between 12,000 and 14,00 species, but only 7,600 (in 250 genera) have been described. In North America, 455 species are found. The major house-invaders include: the thief ant (Solenopsis molesta), the little black ant (Monomorium minimum), the odorous house ant (Tapinoma sessile), the pharaoh ant (Monomorium pharaoni), and the Argentine ant (Iridomyrmex humilis). The last two species will be discussed here.

2. Ants in their natural environment

In their natural environment, ants prey upon a number of insects including certain household pests such as the silverfish and clothes moth. The Argentine ant for example attacks subterranean termites, and also helps aerate hard, dry earth and recycle dead plant and animal material. Ants living in the house help to clean up tiny debris particles -- potential food for even more pestiferous insects. These "pests" are therefore beneficial cleansers and fertilizers, even when not in their natural environment. Species that enter the home generally do not sting, and the ones that bite are not aggressive. Populations of species that regularly nest in the home are not likely to become large if habitat modification and basic controls are maintained.

3. Ants as pests

However, when ants invade the home in search of a meal, they often present a problem. Largely it is an aesthetic one since their presence is thought to reflect poor house-keeping practices. Regular house invaders such as the thief ant, pharaoh ant, or Argentine ant are not usually carriers of pathogenic agents, but foods that they have swarmed over should be disposed of since it can be assumed that they carry organisms which cause spoilage. Pharaoh ants have been found entering wounds, and it is known that they are able to carry over twelve pathogenic bacteria. Researchers in Chile have found that it is possible for the Argentine ant to harbor human enteropathogens such as Shigella flexneri, Staphylococcus aureus, enteropathogenic Escherichia coli, and Bacillus cereus. Management should be directed at removing ants from certain areas of the home, but not at removing them from their natural surroundings.

B. Pharaoh ant and Argentine ant biology

1. Pharaoh ants

The pharaoh ant is a tropical ant that nests where the temperatures are between eighty and eighty-six degrees Fahrenheit. In the continental United States it is most often found in heated buildings, but is occasionally found outdoors if the weather is suitable. Mating occurs in the summer, and more than one queen (each laying hundreds of eggs) may occupy a nest. When kept in the laboratory at twenty-seven degrees Celsius and 80 percent relative humidity, it takes thirty-eight days for workers to emerge from the eggs. Although this species can feed on sweets, it prefers fatty foods, and preys upon bedbugs, white grubs, and other insects.

2. Argentine ant

The Argentine ant is a native of South America but is now established in Arizona, California, Oregon, Washington, Hawaii, Illinois, Maryland, and in southern states. It is a plant pest as well as a house-invader, and has been widely transported by human activity. One aspect of its behavior which seems to have aided its travel is its ability to survive in water. Individuals are known to alternately swim and walk on the surface of water upon which dust has collected. As a group, they can cluster in balls, with immature stages being kept in the center and workers and queens on the outside. Workers continually scramble to the top as more individuals are added and in so doing allow air to reach the immature ants locked in the ball's center. Along with their "swimming" ability, Argentine ants have proliferated because they lack natural enemies, can form extended colonies, and have hardy and numerous queens. While Argentine ants fall prey to the yellow hammer (Colaptes auratus), the English sparrow, and nymphs of the cockroach Thyrsocera cincta, they are basically free of natural enemies in the lands that they invade. Temperature and moisture are the most natural avenues of control.

Argentine ant nests are shallow and often located under boards or rocks, among tree roots, and under the sidewalk. In the summer, the ant nests are small and scattered, but as the weather cools, the colonies coalesce into one larger nest placed deeper into the soil or nearer to artificial warmth. Absence of these ants from drier climates indicates a strong need for moisture.

They are notably drawn to warm moist areas like those offered by decaying plant material. In the early 1900's Newell made use of these facts and found that during cool weather, ants could be lured to a box of compost which could then be fumigated. (Dry ice would be the fumigant of choice today.) During the warm months, Newell found that the ants could be lured to decaying wood placed in a cool spot and baited with a nearby food source (a jar of honey or sugar). After the nesting place was occupied, the infested wood was submerged in boiling water and later reused. Common sense techniques such as these deserve attention and might easily be incorporated into least-toxic control programs.

Unlike other ants, Argentine ants are very friendly with same-species ants from a different colony. This behavior facilitates establishment of extensive community systems that revolve around a common food source, but it also makes their elimination more difficult. In addition, each nest can have more than one queen. These queens are active in feeding and grooming the young, and have been seen travelling along worker trails. Since Argentine ant queens mate when in the nest, they avoid the exposure period experienced by termite reproductives and increase their chance of survival.

To non-species members, Argentine ants are quite aggressive. In fact, they have displaced native ants in certain areas. While doing somewhat of a service by displacing the stinging agricultural pest S. xyloni in parts of California, the Argentine ant has also caused a significant problem in California citrus orchards by protecting honeydew-producing insects from their natural enemies. (Honey dew is a sugar/protein mixture derived from sap plants and exuded naturally by plant-sucking insects).

The extensive range of the Argentine ant can also be attributed to its omnivorous habits. Small insects such as flea larvae, young cockroaches, bed bugs, and other pests are "indoor" foods, whereas thrips and lacewing and ladybird beetle larvae are "outdoor" foods. Food is shared by regurgitation and it has been found that food consumed by one worker can be passed to 156 other colony members in forty-eight hours. Sugars are used most by the workers, whereas proteins are reserved for larvae and the queen. In the past, sugar has been the bait used to carry toxicants such as boric acid. But, it is possible that a greater proportion of the poison could be transported directly to the young if an appropriate mixture of sugar and protein could be derived.

C. Ant detection

Before treatment (preventative or direct) can begin, it is necessary to determine whether or not the invading ant is a carpenter ant. If it is not, the first step is to locate the attracting food source. It is then necessary to find the entrance point and the nest site, and to determine whether the ant is a biter or a stinger.

D. Ant prevention

1. Introduction

Since ants need food, water, and refuge like any other animal, denying them access to any or all of these resources can greatly decrease their number. Measures taken to eliminate ant presence will also help to reduce invasion by other insects such as cockroaches, flour beetles, and moths which are accompanied by their own predators (i.e. spiders, centipedes etc.). Each permanent change will simplify subsequent preventative measures.

2. Elimination of food sources

a. Food storage containers

Reduction in available food sources involves use of appropriate food storage containers, proper management of waste materials, the use of permanent sticky barriers, and modification of habitat. Ants are able to travel up the threads of a screw top jar and enter it if there is no liner or rubber gasket. Therefore, well-sealed jars and plastic containers with snap on lids should be kept handy for food storage. Ants can enter refrigerators but they cannot enter freezers due to their extreme temperature.

b. Management of wastes

By nature, ants are decomposers of organic materials and often seek out wastes on kitchen counters and in garbage pails. To reduce the risk of infestations started in this way, kitchen surfaces should be kept clean, and floors washed or vacuumed frequently. It is further advised that food wrappings and food containers be rinsed before being discarded. Leftovers of any sort are ant-enticing and should be disposed of in sealed receptacles, separate from other types of wastes, and set aside for composting if desired.

3. Permanent sticky barriers

Food goods (e.g. pet food) that must remain in the open can be protected by barriers. Ants will not cross sticky barriers such as Stickem®, Tanglefoot®, or Sticky Stuff®. Dust decreases the effectiveness of these barriers, but a downward-projecting tuna can lid placed above them is a good way to extend their effectiveness.

4. Modification of habitat

Once entry points have been located, silicone caulk can be used to block them off. Silicone seals resists shrinkage from the structure and can be "painted on" (especially helpful in larger areas). Closing off cracks should be accompanied by the use of sorptive dusts or desiccants such as silica aerogel, diatomaceous earth, and boric acid dust.

E. Ant control

1. Chemical control of ants

a. Dusts

Creating a chemical barrier around the house foundation is the traditional approach of pest control professionals. However, it should be kept in mind that some species of house-invading ants (e.g. Argentine ant) patrol the foundations of buildings and act as a deterrent to subterranean termites. The use of non-toxic barriers to prevent intrusion upon living spaces is therefore preferred over foundation barriers. But if the use of caulk and sticky barriers is ineffective, poisons can be used.

Sorptive dusts such as diatomaceous earth and silica aerogel are particularly useful when blown into cracks and wall voids before they are sealed. Boric acid dust can also be used. If kept dry, these materials should be effective for years, and should not harm the residents. No dusts, even "non-toxic" ones should be inhaled.

b. Silica gel-pyrethrum combination

Although the treatments just mentioned are effective, they are also slow to act. For quick knock-down, silica gels can be combined with pyrethrum insecticides. These formulations should be purchased in a container having an applicator which can set the chemicals only where they are needed. Both Revenge™ and Pursue™ have these applicators; Drione™ is a non-aerosol formulation with an applicator like a plastic ketchup dispenser. When dry, these products turn white and are easy to detect. They also present a low level of hazard to mammals, can be easily applied, and work quickly. Unfortunately, they are not cure-alls, and ants are adept at finding new entry routes unless permanent preventative measures are taken.

c. Insecticidal soap

Insecticidal soap or a soap-pyrethrum drench can be used to kill ants directly or to force nest relocation when ants are outdoors but too near a structure. Once nests have been located, the soap (e.g. Safer™ Insecticidal Soap) can be used to saturate the site. (This may have to be done more than once.) If plain insecticidal soap treatments are inadequate, pyrethrum insecticides can also be used to drench the nest. Natural pyrethrum or pyrethrins, derived from an African flower, are less-toxic than laboratory formulations. Eco Safe Laboratories, a supplier of powdered pyrethrum flower heads, suggests soaking 1.5 ounces of pyrethrum powder and 1 teaspoon of coconut oil soap in a gallon of water overnight. Trails and nest areas can be baited with the following recipe: 3 cups of water, 1 cup of sugar, 4 teaspoons of boric acid or borax; hi-protein cat food or a cockroach control bait can be substituted for this mixture. One cup of the bait can be placed into three to six screwtop jars that are packed half-way with cotton, and then saturated with the bait solution. Lids are replaced, and a few small holes are put in each as entranceways.

d. Boric acid baits

Baiting has two major advantages: it uses only a small amount of poison and applies it directly to the target. However, it works only if the target insect can locate the bait, feed upon it, and through grooming and feeding behavior transfer the toxicant to other colony members. Slow-killing toxicants ensure that even developing young are exposed. Larger queens may take longer to kill, and may in fact survive (along with unexposed pupae) after all workers have died off and re-establish a colony. In some ant species, workers can lay eggs which develop into more workers or reproductives. The extensive intercommunication between Argentine ant colonies make their eradication nearly impossible. Given these facts, retreatment does not sound like an unreasonable expectation. Commercially-formulated baits such as Drax^R, by R-Value of Georgia, have become available for use against the pavement ant, thief ant, pharaoh ant, and little black ant. Drax^R is a mint-jelly based boric acid bait which kills both queens and workers. It is formulated as a dust primarily for cockroach control but is also labeled for ants. Most baits are combinations of boric acid and a sugary attractant.

e. Insect growth regulators

Insect growth regulators are available for the control of the pharaoh ant and the fire ant. Pharorid^R, by Zoecon Corporation of Texas, has the insect growth regulator methoprene as its active ingredient. When mixed with an attractive bait, it kills developing young by interfering with the molting process and also sterilizes the queen. Methoprene's negligible acute vertebrate toxicity makes it suitable for residential use. Pharorid^R and Drax^R can be combined into a two phase system, used in conjunction with habitat modification and education of the building's occupants.

Before this combination treatment is initiated, the use of all other insecticides is suspended. Conventional insecticides tend to scatter pharaoh ants, which promotes establishment of satellite colonies and exacerbates the problem. Methoprene is used in the first phase of treatment and relies on the presence of workers for its transferal. If worker number is decreased in this initial phase, less methoprene will reach the queen and brood.

Occupants of the building should be informed that elimination takes two or more months, and that during this time workers (in decreasing number) will still be seen. Worker presence does not indicate program failure; it indicates that the workers are actively transporting the toxicant. The residence should be inspected and feeding and nesting locations mapped. During this part of the treatment, occupant cooperation is essential. All food sources other than the IGR bait must be eliminated in order to maximize the ants' dependence on the presented food. Nest sites such as stored paper supplies, boxes of miscellany, and accumulations of inorganic trash must also be eliminated or isolated on free-standing tables protected by sticky barriers or soapy moats.

It may take six weeks before the Pharorid[R] baits result in a decrease in the number of ants. During the eight week treatment period, seven visits to the bait stations for monitoring may be necessary. Since colonies vary in the foods that they prefer, bait foods should be tested prior to mixing with methoprene. Pharorid[R] comes in a small vial with 10 ml 10 percent AI (active ingredient), and can be stored unopened for two years in the refrigerator. The recommended bait includes two parts liver powder, one part honey, and enough sponge cake to make a seven ounce slurry. A half honey/half peanut butter mixture is also suitable. The bait can be dispensed using a pencil eraser dipped into the solution or as a segment of a "loaded" plastic straw. Each dab or segment can work over a twenty-five square foot area. Baits should be placed next to but not on the ant trails since the latter seems have a repellent effect.

During the first week of monitoring, the baits should be checked three to five days post-placement. Throughout the initial phase of treatment, consumed baits should be replaced. The goal is to get the ants to consume as much of the bait as possible, so if necessary, more baits should be placed in areas where there is the greatest amount of feeding. The stations should be checked weekly for the next two weeks and for the remaining five weeks checked every two. By week eight, the queens should be sterilized although mature starving workers will be wandering around, homeless and unable to feed themselves. These workers should be cleaned up so that the program's effectiveness is apparent. In the second phase of the treatment, the methoprene baits are all replaced by boric acid baits and all areas of entrance and accessway are caulked.

A recent study by Banks, Williams, and Lofgren (1988) investigated the use of insect growth regulators to control red and black imported fire ants, S. invicta Buren and S. richteri Forel. Fenoxycarb is one of a group of chemicals with a carbamate moiety that acts as an IGR against a number of insects. It can be used against cockroaches, mosquitoes, scale insects, psyllids, termites, stored product insects, and some lepitopterous pests. It has been shown to cause alterations in egg-laying and brood development, and eventual death of most treated colonies. The study reviewed here assessed the effectiveness of fenoxycarb in controlling the red imported fire ant (RIFA).

In the laboratory, technical grade fenoxycarb was dissolved at 1.0 and 2.0 percent by weight in refined soybean oil. Oil red dye was added to the solutions as a visible tracer. The oil solutions were administered in 50 or 100 microliter pipettes to laboratory-raised RIFA colonies. Each concentration of the IGR and the control (uncontaminated oil) was tested against at least three colonies. The colonies were given their normal diets twenty-four hours after treatment and held in the laboratory under controlled atmospheric conditions. Each colony was examined twice a week for sixteen weeks, then monthly for a year (by which time most colonies had either died or fully recovered). At every observation, each colony was rated according to the estimated number of workers and the quantity of brood (eggs, larvae, and pupae). Effectiveness of the treatments was determined by comparisons of colony indices (equal to, the value assigned to the number of workers multiplied by the value assigned to the brood quantity).

The oil solutions were readily accepted by the RIFA colonies, although the 2.0 percent solution was removed more slowly than the 1.0 percent solution, indicating possible repellency of concentrated solutions. Dyed integuments proved that a substantial amount of oil had been passed to the larvae within twenty-four hours. All colonies exhibited effects of fenoxycarb relatively quickly, with the most obvious sign being a shift from worker brood to sexual brood production. Decline in worker brood continued until no workers were present in any colony (four to eight weeks post-treatment). At a 5 mg (AI) per colony dosage, seven of the eight test colonies had died by thirty-six weeks; the eighth colony completely recovered by week thirty-two. Three of five colonies treated with 10 mg (AI) fenoxycarb had died in a year; some recovery had occurred in the other two colonies.

Fenoxycarb's exact mode of action is unknown, but the disappearance of worker brood can be due to three possible factors: mortality of the existing brood due to direct toxicity (there is little evidence to support this) or through disturbance of developmental processes, reduction or cessation of egg production, or shift in caste differentiation from workers to sexual forms. Mortality of colonies usually required six or more months and was basically attributed to lack of worker replacement and natural colony mortality due to age.

Four field tests were conducted in Georgia and Mississippi to further evaluate the efficacy of fenoxycarb on natural infestations of RIFA. Six bait formulations were applied to the test plots with a tractor-mounted granular applicator. Similar plots represented untreated controls. The efficacy of each treatment was evaluated by carefully searching the plots before and after treatment, then opening every nest with a shovel to examine its contents. One method used assigned a number to each colony, based on the estimated number of workers and whether or not the colony had a worker brood. Another method employed in the study assigned a rating for size to each nest. The total number of ants per unit area was the number of mounds per category times the assigned average number of ants per mound.

Baits containing fenoxycarb were found to be very effective at reducing the population indices of the RIFA colonies and also the total ant populations in almost all treated plots. Worker number dropped and worker brood was totally eliminated. All the field tests showed that fenoxycarb was effective against natural RIFA populations. An average of 60 percent of the treated colonies were dead thirteen weeks after treatment, and about 33 percent more that had lived until the thirteenth week were reduced to less than one thousand workers. Only about 13 percent of the surviving colonies in treated plots contained any worker brood, whereas about 94 percent of the untreated control colonies contained worker brood. Field testing showed that application of the bait to wet soil and vegetation can reduce efficacy.

2. Biological control of ants

a. Pyemote mite

Although ants have a number of natural enemies, only the pyemote mite or itch mite is marketed for this purpose. It has been used successfully to control fire ants outdoors and may also be useful for killing carpenter ants living in trees. But, it can present a problem for humans and is generally not suitable for use near them.

b. Nematodes

Several species of insect-eating nematodes are commercially available, although there is no data on their use against ants. It is possible that a strain, harmless to humans, could be developed for this purpose.

c. Coordinating colony cycle with treatment

Work reported by Markin in 1970 shows that many ant eggs are produced between late February and early March, and that most sexual forms develop from these eggs. Maturation of these individuals occurs by May and mating occurs inside the nest when females emerge from their pupae. The number of queens remains constant until January or February of the following year when 75 percent are killed off by the workers. Workers are produced in March, reach a number high in October, and decrease thereafter until their number bottoms out in March or April. It has been recommended that control measures be initiated in the fall and that baits be kept available all winter when colony size is dropping and the availability of nectar is low. Full scale control efforts should start before warm weather provides food and opportunity for the mother colony to fragment.

d. Disturbance of feeding trails

Studies done by Dechene (1970) illustrated that major foraging trails of the Argentine ant radiate outward from the nest, and that they are reinforced by ant traffic. A worker will follow the trail for a given distance, then wander up to a foot away to forage. Directionality is apparently not implied in the trail since workers that encounter it will follow it in either direction. It has been found that removing the antennae of workers deprives them of chemical and tactile stimulation, and prevents them from locating trails. Even if a bit of trail is removed, workers will become disoriented. Interference with ant sensory reception is another potential mechanism of control.

3. Physical control of ants

Physically eliminating individual workers will do little to suppress the infesting ant population, especially since new ants are added so quickly. But, it is helpful to mop or vacuum up workers that remain after controls have been implemented.

a. Detergent barriers

Detergent barriers are one way to stop ants from consuming exposed edibles. Water alone is ineffective since ants use the water's surface tension to make their way across non-soapy moats. Adding detergent causes the ants to sink.

b. Flooding

Flooding can be used make ants move from flower pots or away from a given area. A colony existing in a flower pot can be encouraged to move by flooding the plant with water while simultaneously providing an accessway or bridge to an adjacent compost- or soil-filled container. The ants pick up their pupae, head for the pot's rim, and travel across to safer ground. The container can then be removed and disposed of. Hot or cold soapy water is another simple control that can be used to wash nests away from buildings. (Many ants nest outdoors and then wander inside.)

c. Temperature extremes

Like all life forms, ants have an certain range of temperatures outside of which they cannot survive. Most of the techniques related to uses of extreme temperature are used against carpenter ants and have been outlined in the previous section. Ebeling has stated that Argentine ant workers forage day and night, in light and dark. Also, that workers become sluggish at forty-five degrees Fahrenheit and cease activity at forty-three degrees Fahrenheit (activity is resumed if the ants are warmed). The greatest amount of foraging occurs between fifty and eighty-six degrees Fahrenheit. Findings such as these could be incorporated into a control program to target insects when they are vulnerable or to predict when they are most likely to be out and about.

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FLEAS

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FLEAS

I. Identification of problem

Fleas are able to transmit a number of diseases to man. One is plague. Although there have been no reported epidemics in the United States since 1925, the plague is present in the wild rodent population in the western states and a few cases occur in humans each year. Murine typhus is another disease transmitted by fleas, but it primarily affects rats and mice. Transmission of the pathogen is believed to occur when flea feces enters the wound when the host animal scratches. About forty cases of murine typhus are reported each year in the United States. Both people and pets can have allergic reactions to flea bites. However, since humans are often not the preferred host, they are only bitten when infestation levels are very high or when the pet host is absent. Bites on humans occur from the mid-calf down and appear as small red bumps, three to four in a line.

II. Flea biology

Fleas are small, wingless, dark-colored insects with narrow bodies that enable them to move easily between body hairs. Their last pair of legs is modified for jumping and their mouthparts are adapted for piercing skin and sucking blood. Whisker-like spines on their head are used for identification. There are three well-known species of fleas: the cat flea (Ctenophalides felis), the dog flea (C. canis), and the human flea (Pulex irritans). The cat flea can attack dogs, cats, humans, and other animals.

The life cycle of a flea can be divided into four stages: egg, larva, pupa, and adult. Eggs are often deposited on a pet, in the pet's bedding, or in cracks and crevices of floors. In about a week the eggs hatch into worm-like larvae which live not on fresh blood but on organic matter such as dried blood and adult flea excrement. In twelve days the mature larvae change into pupae. If food is plentiful, the pupal stage may last for only seven days; if a host is unavailable, it can extend for over a year. Adults feed more than once a day on fresh animal blood and live for over a year. They can survive for one to two months without a meal, and for eight months having had just one. Since adult emergence is triggered by the presence of a host, reintroduction of a pet can bring about mass emergence.

III. Flea control

A. Introduction

Many conventional chemical treatments are on the market for flea control. They include toxic collars, soaps, dusts, "bombs", and "foggers". Fleas are most often controlled by the use of chemicals applied to an infested pet, indoor areas, or outdoor areas. The brief discussion which follows focuses on the application of chemicals at the first two sites. Due to their toxicity and the generally high level of exposure experienced by pets and people using them, chemicals are not recommended as part of a least-toxic program. Less toxic control techniques are outlined under the last heading of this section.

B. Chemical control of fleas

1. Pets

Pet treatment involves use of one of the following insecticides: carbaryl 5 percent dust, malathion 4 percent dust, methoxychlor 4 or 5 percent dust, or pyrethrins 1 percent dust. (Carbaryl cannot be used on kittens less than four weeks of age.) If combinations of the above are used, component concentrations should be lowered. Preparations usually come as powders, sprays, and shampoos.

2. Indoors

a) Introduction

To eliminate infestations in the house, it is helpful to first vacuum the rugs, floor, and the corners of each room and to dispose of the bag. Application of bendiocarb, chlorpyrifos, malathion, methoxychlor, or a household formulation of pyrethrins kills larvae and adult fleas. Because dusts leave a deposit, sprays are generally preferred. Floors, low wall areas, furniture, and rugs should be treated, but with care since some products can stain.

b) Evaluation of chemicals on appropriate surfaces

The seasonal pest C. felis (Bouche) is a serious veterinary and public health problem. Indoor control has concentrated on larval refugia and laboratory tests have basically involved exposure of C. felis or Xenopsylla cheopsis (Rothschild) to glass surfaces, filter paper, or soil treated with insecticide. Results of these tests have not accurately reflected the efficacy of insecticides when they are applied indoors. A more realistic approach was taken by Rust and Reierson (1988) who applied insecticides to common household surfaces. The following insecticides were evaluated in their experiment: carbamates (bendiocarb, bendiocarb plus synergized pyrethrins, carbaryl, and propoxur), organophosphates (chlorpyrifos, diazinon, malathion, and propetamphos), and natural pyrethrins and pyrethroids (cypermethrin, fenvalerate, permethrin, pyrethrins, and resmethrin).

C. felis larvae were collected from trays set beneath caged cats and allowed to developed in a mixture of sand and dried blood. Several hundred pupae eclosed in a jar with a screened lid which permitted separation of one- to four-day old adults from pupal cocoons. Adults jumped through the screen as the jar was tipped and were then directed onto treatment surfaces via an inverted funnel. Three situations were evaluated. The first involved seven to ten serial dilutions of each insecticide applied to cotton fabric. The fabric was fastened to the inside of a Petri dish and a 1 ml dilution was evenly applied to each of five disks. Fifteen to twenty adult fleas were confined to the treated fabrics under an inverted funnel and the number of survivors counted after twenty-four hours.

Day old residues on cloth provided 50 percent kill in twenty-four hours in this order of toxicity: chlorpyrifos > diazinon = propetamphos > dichlorvos = diazinon 2FM > bendiocarb = bendiocarb + synergized pyrethrins = synergized pyrethrins> carbaryl = dioxanthion = propoxur > fenvalerate = malathion = permethrin = resmethrin. Put simply, the organpophosphate insecticides chlorpyrifos, diazinon, and propetamphos are very effective at killing adult fleas.

Insecticidal activity was also evaluated on both thin and dense nylon carpet with canvas-jute backing. The maximum volume applied was 50.9 ml/m^2 (more spray wetted the carpet too much and caused mildew). The minimum applied was 26 ml/m^2. Residual activity was determined from the mortality found at twenty-four hours among groups of twenty-five fleas confined to each of three pieces of treated carpet. Fleas were tapped from the treated disks into a basin of cold water and the number of living and dead were counted. Control mortality was between 0 and 15 percent.

Day old residues of organophosphate and carbamate insecticides applied at greater than 51 mg (AI)/m^2 killed all adults within twenty-four hours. Rates found for more than 90 percent kill of adults for six weeks were: carbaryl 1222 mg (AI)/m^2, diazinon 509 mg (AI)/m^2, propetamphos 255 mg (AI)/m^2, and chlorpyrifos mg (AI)/m^2. At lower rates only the last two retained activity. Because pre-emerged adults can remain in their pupal cocoon from three to twenty weeks, insecticides must be active for at least twenty-one days in order to affect emerging adults. The length and density of the carpet may have prevented penetration of insecticides into the nap.

The effects of vacuuming, wear, and shampooing on residual control were also tested. A carpet sample was treated with bendiocarb, encapsulated diazinon, or propetamphos. The sample was either left undisturbed or vacuumed with ten sweeps of an upright vacuum cleaner weekly. To simulate walking, a drum-type roller was passed over other sample pieces three times daily. One piece of carpet was treated with each of the three insecticides and rolled and vacuumed daily. Testing also included cleaning a treated carpet with a carpet shampoo machine.

The activity of bendiocarb, diazinon, and propetamphos was not found to differ significantly on undisturbed deposits aged for three weeks. Residual activity of bendiocarb and propetamphos did not decrease significantly when treatments were vacuumed, rolled, or vacuumed and rolled. Activity of microencapsulated diazinon however, declined under the same conditions although it still gave over 83 percent kill. (Crushing the encapsulated insecticide allowed the active ingredient to volatilize more rapidly than if it were left intact.) Shampooing decreased the residual performance of both bendiocarb and microencapsulated diazinon in three weeks but it did not significantly affect propetamphos applications.

Generally, the organophosphate insecticides (except malathion) provided the greatest activity against cat fleas when treated on carpet. Synergized pyrethrins and carbamate insecticides require 1.5-8.8 micrograms (AI)/cm^2 to give 50 percent kill within twenty-four hours. Carbaryl, a commonly chosen insecticide for this insect, was found to be the least active carbamate tested. Very high amounts of pyrethroids (>30 micrograms/cm^2) were needed to provide adequate kill. Determined activity can be summarized as follows: organophosphates > carbamates = synergized pyrethrins > pyrethroids. It should be emphasized that residual activity for three to six weeks may be necessary to interrupt the life cycle of the flea indoors since room conditions can extend the pupal stage.

c) Applications on nylon carpet

The cat flea C. felis (Bouche) has been found difficult to control on carpets using residual sprays. The problem may relate in part to insecticide resistance. In fact, a study by El-Grazzar, Milio, Koehler, and Patterson (1986) found that tolerance to as many as nine insecticides occurred in a single strain of cat flea. Koehler, Milio, and Patterson (1986) conducted a study to determine the residual toxicity to cat fleas of commercially prepared insecticides when applied to carpets.

Fleas were reared on cat hosts at the ARS-USDA Insects Affecting Man and Animals Research Laboratory in Gainesville, Fla. Commercial preparations of microencapsulated pyrethrins (0.16 percent), bendiocarb (0.50 percent), bendiocarb and pyrethrins (0.50 percent), propetamphos (0.50 percent), microencapsulated diazinon (1.00 percent), and chlorpyrifos (0.25 percent and 0.50 percent) were diluted in 100 ml water to the above concentrations, and applied to the carpet at label rates with a track feed sprayer at 1.41 kg/cm^2, 46 cm above the carpet. Short pile carpet samples (12.96 strands per cm nylon double thread, 1 cm height, jute backing) were treated individually with an insecticide and allowed to dry for four hours. Each sample was then cut into thirty-six square inch pieces which were allowed to age and were subsequently evaluated in the laboratory at twenty-six degrees Celsius and 50 percent relative humidity. Carpet residues were evaluated at one, two, four, seven, fourteen, and twenty-one days posttreatment. At each of these times, five samples were picked at random for each compound and placed in a 250 ml glass hydrometer cylinder. Ten cat fleas were placed on the carpet in each cylinder. After twenty-four hours, the carpet was removed and examined for living and dead fleas.

All the insecticides except 0.5 percent bendiocarb and 0.16 percent microencapsulated pyrethrins caused mortality one day posttreatment. But by day two, the 0.5 percent bendiocarb and 0.25 percent chlorpyrifos also failed to cause significant mortality. Fourteen days posttreatment 0.5 percent bendiocarb and pyrethrins, and twenty-one days posttreatment 0.5 percent propetamphos failed to provide significant mortality. High levels of mortality were achieved but high levels of control were not. At two days posttreatment, only 0.5 percent chlorpyrifos caused more than 80 percent mortality. It caused greater than 90 percent mortality for a week before its efficacy declined.

From this study it can be concluded that insecticides applied to nylon carpet (one of the most commonly treated surfaces) do not provide long-term protection against fleas. Registered insecticides provided control only for one to seven days. Three factors seem to be contributing to this finding. One is that carpet has a greater surface area per square centimeter than other treated surfaces, therefore less active ingredient per unit area is present. Second, carpet density prevents complete coverage of the treated area. Third, since the carpet is a synthetic organic material, synthetic organic pesticides may be moving into the fiber matrix and becoming unavailable to the fleas. Poor residual control is the net result of these factors. New formulations and application procedures appear to be necessary. Insect growth regulators represent an effective alternative to these conventional insecticides.

3. Outdoors

Outdoor methods of control should begin in the summer and early fall. One of the following chemicals can be used: bendiocarb, carbaryl, chlorpyrifos, diazinon, malathion methoxychlor, or propoxur. All safety measures detailed on the label should be followed.

C. Less toxic flea controls

1. Fatty acids, pyrethrum, and limonene

Safer, Inc. of La Mesa, California offers a variety of products for insect control in the house, in the garden, and for pets. Entire™ Flea and Tick Spray is a combination of fatty acids and natural pyrethrum that can be applied to pets and to infested areas. Fatty acids are a basic energy source and a building block of cell membranes. A select few can serve as insecticides by penetrating the body of a susceptible insect and acting as membrane disruptors. Essentially the fatty acids "punch holes" in the cell membrane by binding to carbohydrate or protein receptors. This alters normal membrane permeability and cellular physiology and causes the cell contents to leak out, resulting in the rapid death of the insect or mite. Unlike conventional petrochemical-based insecticides, fatty acid formulations need not be ingested by their target. They are also biodegradable, do not accumulate in the food chain, and can be combined with other chemical formulations to create a broad spectrum insecticide.

Once the formulations are dry, they are no longer effective. Safer™ Indoor Flea Guard and Safer™ Flea Soap for Dogs and Cats are combinations of potassium salts and fatty acids. (The salts upset the ion balance of the membrane.) Two other products by this company (Insecticidal Soap for Houseplants and Mite Killer) are also based on these ingredients and are used against red spider mites and two-spotted mites. It is also known that limonene, a citrus fruit extract, is effective at repelling fleas.

2. Diatomaceous earth, pyrethrins, and methoprene

Diatomaceous earth, mentioned previously for the control of termites and ants, can also be sprinkled into furnishings frequented by flea-ridden pets. Pyrethrins (esters of pyrethrum, an extract from the chrysanthemum plant) and the insect growth regulator methoprene are other alternatives. Pyrethrins are very toxic to fleas but have low mammalian toxicity. Methoprene works by interfering with flea development and also has relatively low mammalian toxicity. Researchers at the Bio-Integral Center have stated that methoprene is active for six months against developing fleas.

3. Pet care, "lures", and vitamins

Restricting a pet to a single bed enables the owner to wash bedding frequently to remove adult fleas and larvae. Bathing an animal and grooming it with a metal comb (dunked into soapy water after each stroke) can also decrease the number of fleas. If homeowners are planning to be away for a few days, a goose-necked lamp left lit on the floor above a bowl of soapy water can act as an attractant, drowning enticed fleas. Taking vitamin B_1 as Brewer's yeast has been found to reduce the frequency of flea bites. (This form should be given to pets in small quantities to avoid cramping.) B-complex vitamins serve the same purpose.

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TICKS

I. Identification of problem

II. Tick biology

III. Tick prevention

IV. Tick control
   A. American dog tick
   B. Brown dog tick
   C. Repellents

TICKS

I. Identification of problem

Ticks cause and transmit a number of diseases. Dermatitis for example is caused by the tick's secretions or its bite. Tick paralysis is another condition known to affect cattle, sheep, dogs, and humans (especially children). It is believed that a poison passes from a feeding female tick to the host. In humans, the initial symptom is loss of feeling and muscular coordination in the legs, followed by paralysis which continues up the body to the arms, throat, heart, and lungs. Although death is possible, recovery can be rapid if the tick is located and removed. Both the wood tick and the brown dog tick can cause this ailment.

Rickettsia rickettsii, the disease organism responsible for Rocky Mountain spotted fever, is transmitted by the American dog tick. Most cases occur in the eastern United States and men, rodents, and rabbits are all susceptible. Two weeks after being bitten by an infected tick, a body rash will develop, accompanied by high fever, headache, and muscle pain. Antibiotics and vaccinations are available to treat this disease, but since ticks wander about their host for as long as two hours before they settle down to feed, the best way to prevent transmission is to catch the tick while it is still moving. A pregnant female tick can acquire the disease by biting an infected host and pass it on to her offspring. This transferral can go on for six to eight generations. The magnitude of the problem is easily seen when one considers that a single female can lay over six thousand eggs.

Tularemia, a disease of rabbits and rodents, is highly infectious to man and can occur through transferal of ticks, through contact with the tick's body fluid or feces, or by contact with an infected rabbit or rodent. The disease agent is able to penetrate unbroken skin. Symptoms include swelling at the bite site, swollen lymph glands, fever, muscle pain, and weakness which can last for months. Anemia and death are possible results of transmission. The American dog tick and the brown dog tick are both carriers of this disease.

II. Tick biology

Ticks and mites belong to the class Arachnida. Unlike the members of the class Insecta which we have been discussing, adult ticks have eight legs and have neither antennae, compound eyes, wings nor body segments. All are parasitic and live on the blood of vertebrates. The three species of ticks to be considered here are: the American dog tick (Dermacentor veriabilis), the brown dog tick (Rhipicephalus sanguineus), and the lone star tick (Amblyomma americanum (L.)). The second species is an important household pest but only a potential vector of disease since it generally does not attack man. A. americanum, found throughout the southeastern United States, is a primary concern because its presence on dogs can permit pathogen transfer to humans.

The American dog tick is inactive in the winter but it can be found ready and waiting to attach to a passing host in the spring and summer. Since it will not establish itself inside the house, indoor control is unnecessary. In contrast, the brown dog tick can live in the home year round and uses dogs almost exclusively as hosts. Various features can be used to distinguish between these two ticks. For example, the basis capituli (base of the mouthparts) has rounded ends in the American dog tick but pointed ends in the brown dog tick. The scutum or back plate of the ticks is another distinguishing feature. Its color tells the species and its size tells the sex. The scutum of the American dog tick has silverish or whitish markings which stand out from the color of its back whereas the back of the brown dog tick is all one color. In males, the scutum covers the entire back but in females only the front part of the back is covered.

The life cycle of the American dog tick takes about two years to complete and goes as follows. In the spring, females lay 4,000 to 6,500 eggs. The eggs hatch into six-legged "larvae" which actively search for food (rabbit or rodent blood), although they can live up to a year without any. Once a larva finishes its meal, it drops to the ground and molts into a nymph. The nymph must then locate another rodent host. Once the adult form is reached, the tick is able to select larger host such as dogs and cattle. Once an adult female has engorged herself, she is able to lay eggs. Adults can live for two years without food.

All stages in the life cycle of the brown dog tick rely on a dog for a host. Between meals, the tick hides in crevices in the house. Breeding in the house is unaffected by the change in seasons so any stage is likely to be found on the dog or in the house at any one time. The brown dog tick will occasionally use man as a host.

III. Tick prevention

Preventative measures start with thorough examination of animals or people that are returning from an outing. If a tick is found feeding, it needs to be irritated enough so that it will withdraw. Applying alcohol or gently pulling the tick off with tweezers should do the trick but this procedure should be done carefully so that its mouthparts are not left behind. The wound should be cleaned with antiseptic and the remover's hands washed to eliminate germs present in the tick's secretions.

IV. Tick control

1. American dog tick

Appropriate control measures again center around knowledge of the species type and its behavior. With regard to the American dog tick, it is only necessary to remove the ticks from the dog. But if the source of ticks is an area around the home, that area can be sprayed with carbaryl, diazinon, chlorpyrifos, or propoxur.

Koch and Burkwhat (1983) established and compared base-line data on the effectiveness of a number of acaricides against an Oklahoma strain of D. variabilis. Collection of such data is useful in detecting the development of resistance and in selecting acaricides for further study. Larvae fed on domestic rabbits and were later placed in covered plastic containers and allowed to molt under controlled atmospheric conditions. Because studies involving A. americanum have shown that susceptibility is dependent on age, the nymphs selected for the study were five to seven weeks post molt.

First, the acaricides were dissolved in acetone. Then, 1-ml glass pipettes were immersed in the proper acetone dilution and allowed to dry for twenty minutes. (This period may have allowed dichlorvos to vaporize which resulted in its reduced residual effectiveness.) The larger opened ends were covered with cloth and secured with a latex band and the smaller ends broken to permit entry of the ticks. Ten nymphs were aspirated into each treated or untreated tube with a vacuum pump and the narrow broken off tips resealed with clay. All pipettes were held for twenty-two to twenty-four hours at about twenty-seven degrees Celsius and over 90 percent relative humidity. Mortality counts were then immediately made. Ticks were considered dead if they did not respond when prodded or blown upon. LC_{50} and LC_{90} values (lethal concentrations) were determined from the tests using an average of eight replicates for the six acaricide concentrations used.

Results showed that the carbamates propoxur and bendiocarb were the most effective acaricides. Lindane, amitraz, chlorfenvinphos, and carbaryl were the next most effective, with nearly identical LC_{50}s. Ronnel, malathion, and rotenone were found to be the least effective compounds. Results proved that several acaricides are effective against D. variabilis.

Field evaluation of free-living populations has been performed by Koch, Burkwhat, and Tuck (1985) using A. americanum (L.). Their study described a method used to evaluate acaricidal dips for dogs and reported results obtained from certain marketed products. Male and female beagles one to three years old and of medium weight were obtained from a professional handler. Woodlots with concentrations of A. americanum were located in Cherokee County, Oklahoma. Sample sites were flagged with surveyor's ribbon and on the first testing day dry ice was placed on the ground to stimulate host-seeking activity.

Thirty minutes later, three leashed dogs were brought to each site. The groups of dogs were moved to different sites after fifteen to thirty minutes and then removed from the area after an hour total exposure. Four to five hours later, attached adults and nymphs were counted by inspection before the dogs were housed in an outdoor kennel near the laboratory.

Tick-infested dogs were randomly assigned to treatment groups (three per group). Each dip was prepared according to label recommendations by mixing the calculated dose in about 15 liters of tap water. Each dog was completely submerged for several seconds and then penned singly or with a dog of the same treatment group to prevent cross-contamination. One group of dogs in each trial was dipped in water and served as a control. Live ticks (those that moved normally) were counted and removed twenty-four hours after treatment; dead ticks were noted and also removed. Infestation rates averaged one-hundred ticks per dog during the two years of study. Treated groups were returned to the lots at three, seven, twenty-one, twenty-eight, and thirty-five days after treatment to determine the residual activity of each acaricide. (Treatment groups showing no mortality were not exposed to the ticks.) After exposure, counts were again taken at four or five hours and again twenty-four hours after exposure (the delay allowed time for ticks to attach). Most host grooming was noted during the attachment period, although removal of attached ticks was found to be minimal.

Results of the tests showed that all the acaricides tested (except for pyrethrins) caused complete mortality of A. americanum (L.) attached to dogs on treatment day, but that levels of activity dropped for all the acaricides thereafter. Because ticks attached, it is assumed that the tested acaricides lack repellent properties. This testing method employed natural populations and infestations, but because there was a decline in the average number of ticks per untreated dogs it also proved that an unequal ectoparasite pressure existed. Population fluctuations are often encountered in field trials and complicate interpretations of results. A similar method of study was used by these researchers to evaluate the effectiveness of acaricide-impregnated dog collars against A. americanum. Similar studies using the American dog tick or the brown dog tick are possible.

2. Brown dog tick

If the brown dog tick is the problem, both the home and the dog must be treated. Dogs can be dusted with one of the following: 5 percent carbaryl, 5-10 percent methoxychlor, 3-5 percent malathion, 1 percent rotenone, or a commercial tick or flea powder. Cracks and crevices in the house and the dogs bedding should be treated carefully, using either 5 percent malathion dust or a 2 percent to 0.5 percent diazinon spray. Rugs and furniture should be vacuumed. During the warm months it may also be necessary to treat areas around the home.

3. Repellents

The following can be used as repellents when visiting areas likely to be infested with ticks: diethyltoluamide, ethyl hexanediol, dimethyl phthalate, dimethyl carbate, Indalone and benzyl benzoate. Protection lasts only a few hours.

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BEETLES

I. Cockroaches

A. Identification of problem

One of the most well known but least popular insects is the cockroach. There are over 3,500 species existing throughout the world, fifty-seven of which are found in the United States. The truly pestiferous species are German, brown-banded, Oriental, smokeybrown, and American. Cockroach presence is considered "socially unacceptable", and the insect's unpleasant odor and ability to contaminate food with disease organisms make finding alternative methods of control a worthwhile pursuit. The German cockroach is the most widespread pestiferous species, its cosmopolitan distribution due largely to man's dispersive tendency. It is known to cause allergic reactions in 61 percent of asthmatics and 27 percent of nonatopic children. Cockroaches have been linked with transmission of the pathogens that cause food poisoning, toxoplasmosis, infectious hepatitis, polio, and amoebic dysentery.

Koehler, Patterson, and Brenner (1987) found that, out of 1,022 apartments surveyed in north-central Florida, 97.5 percent were infested with German cockroaches. Data indicated that half of the apartments had over 13,000 cockroaches, with the average apartment having 19,647 cockroaches. Although monthly control measures were followed in some cases, apartment dwellers still faced unacceptably high infestation levels and constantly risked exposure to pathogenic agents carried by the cockroaches. Resistance of the insect to currently used pesticides is probably a contributing factor. The need to re-evaluate conventional treatment techniques is clearly pertinent, as is the need to more extensively explore alternative measures of control.

B. Cockroach biology

1. Appearance of adults

The adult German cockroach (<u>Blattella germanica</u>) is about a half-inch long with two dark stripes on its thorax; young are one-sixth to one-half an inch long. The brown-banded cockroach (<u>Supella longipalpa</u> (F.)) is similar to the German cockroach in size, but has two light-colored stripes across its body. Adult Oriental cockroaches (<u>Blatta orientalis</u>) are black and about an inch long. Adult American cockroaches (<u>Periplaneta americana</u> (L.)) are 1.5 inches long.

2. Likely habitats

Cockroaches are found in caves, animal nests and burrows, and human habitats. They commonly dwell in restaurants, eating areas, and bathrooms where food and water supplies are plentiful. Warm, moist microclimates such as these are similar to those found in their native tropical habitat, East Africa.

German cockroaches prefer kitchens and baths but are occasionally seen outdoors and can exist in heated buildings as far north as Alaska. Although less abundant than the German cockroach, the brown-banded cockroach presents a more difficult control problem since it can tolerate drier conditions and will roam throughout establishments. This species is a major urban pest across the United States but is especially troublesome in the South.

Adult Oriental cockroaches emerge from heat tunnels, sewers, and similar places in the spring and may then invade buildings. They can live year round in basements and are often seen in the summer and fall in lit outdoor areas. American cockroaches also inhabit the lower floors of buildings and can live in dumps, wood piles, and sewers if the weather is warm. They are the most avid fliers of the group. The smokeybrown cockroach is common in southern states and lives in wood and debris piles unless cool temperatures or lack of food drive it indoors.

3. Cockroach life cycle and daily behavior

Female German cockroaches carry their egg capsules (oothecae) for most of the incubation period (other house-invading cockroaches simply deposit them in a safe place). The incubation period is temperature dependent but at eighty-five degrees Fahrenheit it lasts twenty-three days. Thirty-five to forty-three nymphs emerge from each ootheca, and individuals go through six or seven instars before molting into adults. The average development period (nymph to adult) is also temperature dependent but lasts seventy-four days at eighty-five degrees Fahrenheit. Female German cockroaches can live for over six months and produce about four oothecae (most other cockroaches produce offspring only once). German cockroaches are thus the most prolific of these species.

During the day cockroaches hide or rest in dark narrow spaces such as cracks and crevices in or near human dwellings, but at night they forage. German cockroaches become active as soon as twenty minutes past dark; their activity increases until it peaks near daybreak. The easy access to harborage and other resources offered by most buildings make cockroach cohabitation with people ideal (for the cockroach that is).

C. Cockroach detection

1. Means of entry

Cockroaches can enter a living unit from outdoor buildings or dumps, or from an adjacent apartment. Pathways include heat tunnels, plumbing, structural gaps between buildings, and elevator shafts. Cockroach eggs can be introduced into buildings by grocery cartons and sacks of vegetables.

2. Monitoring existing populations

Cockroach presence is indicated by living or dead cockroaches, cockroaches in traps, caste skins of different stages, empty egg cases, or fecal droppings. Once cockroach presence is established, a monitoring program can be initiated. Using a flashlight, and pen and paper, a floor plan of the infested area can be drawn up for note-taking. Monitoring is particularly important when combating roach problems not only because it locates infestations precisely in time and space, but because it establishes a baseline population size from which to determine the most cost-effective treatment program. For example, data collected through monitoring can pinpoint where population density is highest and consequently where to concentrate control efforts. Monitoring, as stated before, also aids in evaluating the effectiveness of instituted control methods.

Cockroach presence is usually assessed by flushing out the insects with a pyrethrin aerosol spray. The use of traps however is a more effective indicator than either flushing out or trying to visually count the cockroaches. Most of the commercially available traps are modeled on a prototype developed by Zoecon Corporation of California. They usually consist of a small rectangular cardboard box which has three bands of sticky glue inside. Some offer baits such as burnt molasses. When and how often to place traps is determined by the size of the given population, the type of infested location, amounts of competing attractants, and the resources and skill level associated with the particular monitoring program. Aside from their use in monitoring, baited traps can be used to a certain degree as control tools, say for catching immmigrants in a "clean" area or when insecticide use is impossible. Populations of cockroach natural enemies can also be monitored, but this type of monitoring requires special knowledge and must be done in accordance with the sort of enemy (microbe, parasitoid, predator) being trapped.

Another way to sample populations is with a jar trap (often used in scientific experiments). The trap is usually a 128 ml baby food jar coated with grease on the inner surface to deter escapees. Two to three grams of white bread or beer may be used as bait. Although this method is biased towards nymph-catch, it is reasonably well standardized as opposed to the visual counting and flushing techniques (however, these also include a good deal of monitor bias).

Once a monitoring program has been established, control measures can begin. Action is required when the pest population threatens to reach or exceed the injury level. (A discussion of the aesthetic injury level preceeds the topic of control.) No absolute cockroach population level is used to indicate an unacceptable degree of injury. Instead, this level is defined for each treatment site. Contracts with pest control operators should outline precisely how the situation's action point will be determined, given the information obtained by monitoring the population.

D. Cockroach prevention

1. Anticipation of cockroach mobility

One major consideration in developing an effective method of control is that cockroaches are always on the move. The battle to prevent their recurrence can be constant and some believe that the best preventative measure is chemical treatment of an area every two to four weeks so that newcomers are killed and re-establishment avoided. It has been found that urban interapartment travel can be as high as 30 percent per week.

Runstrom and Bennett (1984) examined this movement through a mark-recapture study of German cockroach populations in urban apartments. A total of four buildings, each having four apartments, were used. The floor plans for each were the same except that adjacent units were mirror images of eachother. That is, certain sets of kitchens and bathrooms were back-to-back and serviced by a common plumbing system that divided the wall voids between the units. About forty jar traps were placed in each apartment overnight. All captured adults were marked on their pronotum with a colored numbered tag (a different color was chosen to represent each apartment for the given week of study) Once tagged, the marked individuals were released into the site of capture. Traps were set up in each apartment three more times at weekly intervals. A total of six thousand adults were tagged and sexed, and each was uniquely identified.

Insecticide was applied in individual apartments after the third week of trapping to determine the effect on movement. The apartment with the highest trap catch (greatest potential for dispersion) was treated with chlorpyrifos (0.25 percent) plus dichlorvos (0.25 percent). The other three apartments in the building were monitored for twenty-four hours to check for dispersion from the treated room. Recapture rates averaged 14 percent for all apartments. Of all the recaptures in a given apartment which were "immigrants", 75 percent came from an adjacent apartment having a common plumbing connection. In thirteen of sixteen apartments, recaptures coming from adjacent apartments were greater if the apartments were joined by plumbing connections than if they were not.

Analysis of movement after pesticide application revealed no significant effect on movement rates. Even though the pesticide used contained dichlorvos (a flushing agent), movement out of the treated area twenty-four hours after treatment was not significantly different from that exhibited before treatment. However, movement into treated areas was decreased in all cases after pesticide application. Apparently a good deal of cockroach control relates to modification of existing structures to inhibit movement between living units.

2. Habitat modification

a) Eliminating water sources

Habitat modification entails permanent preventative alteration of the environment through elimination of attracting resources. It has been found that female German cockroaches can survive eighty days with food and water, but only thirteen without them. It has also been found that females live longer (forty-two days) on water alone than food alone (twelve days) when kept at twenty-seven degrees Celsius. Further, that survival increases with higher relative humidity. Obviously, reducing water and humidity are key to lowering cockroach survival.

Sources of drinking water include condensation around windows and pipes, leaky plumbing, and water-filled containers such as those used for pets or for catching leaks from appliances. The installation of barriers can sometimes help to eliminate these attractants, but since reduction is often insufficient building modification and food removal are most often the chosen paths of prevention.

b) Eliminating food sources

Sanitation is another important aspect of prevention. Food lodged in hard-to-reach places such as in cracks, beneath baseboards, and behind cupboards encourages infestations, as do opened packages of edibles. Glass or pressure-sealed plastic containers should therefore be used to store food (cockroaches can chew through paper and cardboard). Special efforts need to be made in restaurants and food processing areas in recreational and business establishments. In these areas garbage pickups should be increased, especially if infestation levels are high or chronic. Garbage containers, even if used with plastic liners, should be cleaned regularly since all residues are attractive to cockroaches. Effective population reduction in infested establishments requires careful examination and alteration of maintenance procedures.

In a report which examined insecticide efficacy, cockroach resistance, and the role of sanitation in control of the German cockroach, Coby Schal (1988) stated that there was a positive correlation between poor sanitation and higher cockroach populations. Moreover, that poor sanitation lowered the efficacy of otherwise effective insecticides. In some treatments, he found that improved sanitation increased the efficacy of the insecticide. Results such as these not only point to the role of sanitation in cockroach control but they also emphasize the interrelatedness of components in any least-toxic management program.

c) What attracts cockroaches

Several types of compounds are thought to aid insects in finding food. Many are products of the degradation of proteins and fats, others are microbial components or products of fermentation. Compounds which have been considered include fatty acids, esters, and alcohols. Products of animal decay (amines, indoles, and sulfur compounds) are usually less attractive. Roaches prefer diets high in carbohydrates with a minimum of fats and protein. Breads are at the top of their list (as are the dregs of a beer bottle), but response to animal proteins is very low. Cockroaches probably choose among many volatile compounds present in the air to locate desirable foods.

Isolation of attracting components can serve in directly reducing cockroach number, in luring the pests to pathogens or poisons, and in facilitating monitoring procedures. Although carbohydrates and sugars stimulate feeding in insects, their volatility is low and they probably could not act as long-distance attractants in baits. Work with pheromones baits has not been as effective as anticipated, results being complicated by the fact that the studied pheromones must be perceived by touch.

d) Sealing potential harborages

Cockroaches are thigmotactic, that is, they prefer to have their bodies touching the substrate. Spaces that accomodate this need are easily found in poorly constructed or deteriorating buildings. Adult German cockroaches can hide in cracks as small as 1.6 mm wide and first instar larvae can squeeze through areas 1 mm wide. Such spaces should be caulked or otherwise sealed according to the size and location of the gaps. In residences with many cracks and crevices, sealing should begin when monitoring indicates that populations are highest. Other preventative steps include weatherstripping openings, replacing or repairing windows and screens, and realigning doors. Air vents like those found in kitchens can be screened to prevent cockroach entry.

E. Cockroach control

1. Aesthetic injury level

The principles of integrated pest management (IPM) were first tested and found effective within the context of agriculture. But as IPM has expanded to include other ecosystems, various factors have demanded consideration. For example, where urban pest management programs are concerned, there is a need to understand the close association between the target pests and man, and to consider the sociological and physiological demands of the public. Changes in relevant factors have led to an alteration of the basic aim of IPM programs as they are applied to certain situations. In agriculture, the aim remains to establish an economic injury level (EIL)-- the lowest pest population capable of causing economic damage-- and to avoid total eradication of the target population. While an EIL centers on management techniques, urban IPM programs often involve strict control measures dictated by prevailing attitudes and trends regarding the pest. When Olkowski set up an urban IPM program for street trees in Berkeley, California, he established an "aesthetic" injury level (AIL). The reasoning behind it was that problem assessments are not always seen in economic terms; aethetic considerations are sometimes also necessary before treatments are pursued. I have introduced this concept here because it relates most strongly to cockroach control.

Zungoli and Robinson (1984) conducted a survey in federally subsidized public housing projects in Maryland and Virginia to determine the attitudes of the residents towards the presence of cockroaches in their homes. Results showed that 83 percent of the residents surveyed perceived cockroaches to be a serious problem. Association of the pest with food was found to be particularly intolerable. Many residents expressed a feeling of hopelessness concerning their ability to control the pest. Thirty-nine percent of the residents did not believe that total elimination of the cockroaches was possible and, of these, 72 percent believed the problem was attributable to factors outside their control (e.g. neighbors, lack of cooperation, cockroach movement). Those experiencing the heaviest infestaions were willing to pay the most for control.

It was also found that thirty-four percent of the residents take action if they see one cockroach; 55 percent tolerate zero to two cockroaches before they respond. For a control program to satisfy 45 percent of the residents, it would have to ensure that no greater than one cockroach would be seen in a twenty-four hour period. Needless to say, such minimal tolerance of this pest necessitates development of high caliber control techniques not only to achieve a very high initial suppression goal but also to maintain a consistently high level of effectiveness. In addition, resident would have to be educated regarding the causes of infestations and encouraged to cooperate with other tenants. An underlying part of least-toxic control programs is a certain degree of tolerance on the resident's part. But, as this study shows, aesthetic tolerance can sometimes be so low as to make establishment of an AIL impractical.

2. Chemical control of cockroaches
   a) General use of chemicals

Typically, liquid or aerosol ant and roach sprays, or baits are the chosen methods of cockroach control. The sprays contain quick killers or irritants (e.g. pyrethrins) plus a long-lasting insecticide and are applied regularly to places from which cockroaches emerge. They are also used to drive out Oriental and American cockroaches hiding in openings around pipes and drains in basements. Popular synthetic chemicals include organophosphates, carbamates, and pyrethroids. Chlorpyrifos, diazinon, propoxur, propetamphos, and pyrethrum (pyrethrins) have all been associated with adverse health effects and cockroach resistance to many has been found. Alternatives include boric acid, amidinohydrazone, and hormone analogs. The acute toxicity of the synthetic insecticides just listed is over five times that of boric acid. Pyrethrum is 25 percent more toxic than boric acid. Boric acid comes in a non-volatile formula and may contain less than 1 percent inert ingredients compared to the over 50 percent found in synthetic formulations. (Inert ingredient content is a serious concern since inerts remain largely untested for association with adverse health effects.) Aside from the risk to the pest control operator, continual use of harmful insecticides encourages the development of resistance in the target pest and prolongs exposure of the environment to adverse effects.

b) Some aspects of resistance
   (1) Responses to propoxur (a carbamate insecticide)

Widespread use of insecticides has affected insect populations in two ways. One is the development of physiological resistance, the other is behavioral change. Bret and Ross (1985) found that a propoxur-resistant strain of B. germanica dispersed less than a susceptible strain when exposed to propoxur vapors. In fact, the resistant (BP) strain was found to be seven to eight times more resistant than the susceptible (VPI) strain. The selection for avoidance behavior due to insecticide pressure has been positively correlated with physiological resistance in certain species. A study by Ross and Bret (1986) detailed the excitatory behavior elicited by propoxur in terms of movement and grooming response.

Adult B. germanica males from both the BP and VPI strains were used. In each replicate five males of the chosen strain were confined on a piece of filter paper. Below them was placed an aluminum pan containing the chosen solution and a wire screen to prevent direct contact between the cockroach and the chemical. A glass chimney, coated with petroleum jelly on the inside to prevent escape and covered with a glass plate, was placed above the cockroaches. Two out of the five cockroaches in each replicate were marked with a dot of white correction fluid. Movement in the set up was recorded with a video camera for five minutes after exposure. When the video was played, movements were traced using a piece of acetate placed over the television screen. Eight repetitions were performed under the same controlled conditions. The number and rate of antennal and tarsal cleaning motions performed per minute for half an hour were also visually recorded. Ten replicates, each the sum of five individuals, were completed for each strain.

Experimental results indicate that exposure to propoxur vapors causes an increase in movement and in antennal and tarsal cleaning compared to that seen in controls. Control cockroaches moved about the entire arena, going around the perimeter as well as crossing its center. In contrast, exposed subjects concentrated nearly all their movement at the perimeter. This pattern was considered an avoidance response (an attempt to move away from the source of irritation). BP males moved about more than VPI males in both test and control situations, but the change of response between control and exposed conditions was greater for the VPI males than the BP males.

Antennal grooming to remove the irritant from chemoreceptors involved downward movement of the antenna and flexion of the prothoracic leg over it to direct it towards the mouth. Mandibles moved in a chewing motion along each antenna from base to tip. (Tarsal grooming involved similar use of the mouthparts, with most effort spent on the prothoracic legs.) No rate changes between controls and test subjects existed. But, upon exposure to the vapors, VPI males cleaned more frequently and showed a 9.5-fold increase in the total number of antennal cleanings over the controls; BP males showed only a 5.4-fold increase. Loss of motor coordination due to intoxication eventually resulted in a decrease in antennal grooming.

Exposure to the chemical caused a steady increase the frequency of tarsal cleanings, with VPI males exhibiting a greater increase than BP males. Results were partially influenced by accumulation of petroleum on the antennae, lack of harborage, and a relatively short period of acclimitization. Nonetheless, the degree of change seen in each strain when compared to control groups is significant, and points to a correlation between the development of resistance and the expression of decreased sensitivity to insecticide vapors.

(2) Effects of synergists on bendiocarb and pyrethrin resistance

Resistance to bendiocarb is supposedly the most widespread resistance problem in B. germanica. However, resistance that is metabolic in nature can be negated through use of synergists such as piperonyl butoxide. Cochran (1987) examined the effects of synergists on reducing bendiocarb resistance and compared the effects of different synergists on resistance to natural pyrethrins in the German cockroach. Nymphal cockroaches of a variety of strains were used in the experiment. Ten subjects were placed in each of three jars which had been coated on their interior with known amounts of chemicals. Time/mortality responses were recorded until 90 percent of the cockroaches were mortally affected. Data from the three replicates was pooled and statistically analyzed. LT_{50}s were calculated for each strain for each chemical, and resistance ratios (RR's) were also found (LT_{50} resistant strain, R / LT_{50} susceptible strain, S). The chemicals tested were: pyrethrins alone and with the synergists (piperonyl butoxide or PBO, and MGK 264); bendiocarb (Ficam W) alone and with the synergists; and pyrethrins plus bendiocarb with and without synergists and bendiocarb (Ficam Plus). Bendiocarb was applied at the rate of ten micrograms per square centimeter and pyrethrins at the rate of three-tenths of a nanoliter per square centimeter. Synergist concentrations were related to insecticide concentrations in definite ratios (e.g. 1:1, 1:10, insecticide to synergist).

As would be expected, neither synergist modified reponses of susceptible strains. But, MGK 264 rendered all but one resistant strain almost totally susceptible. PBO was not as effective at lowering resistance. Using two of the strains (Mandarin and Kenly) and ratios of 1:2 and 1:3, it was found that increased amounts of synergists decreased the resistance ratios. These strains were also tested with natural pyrethrins, with and without synergists. Kenly was found to be highly resistant whereas Mandarin exhibited low resistance levels. A small decrease in the RR for the Mandarin strain was recorded for use of both synergists. Further testing of the strains with bendiocarb plus pyrethrins and with or without synergists uncovered an optimum ratio of 1:10 for pyrethrins and 1:3 for bendiocarb. Both of the synergists reduced the resistance ratio in both strains.

It can be concluded from this experiment that resistance to pyrethrins and bendiocarb in the German cockroach can be negated through the use of PBO or MGK 264 as synergists. Also that commercial formulations of mixtures of these materials would lower the resistance of a given strain. Ficam Plus (bendiocarb, pyrethrins, and PBO) was used in this experiment and it did in fact decrease the resistance of both bendiocarb and pyrethrins. Supposedly, synergists act as inhibitors of microsomal mixed-function oxidases.

(3) Pyrethroid resistance

Pyrethroid insecticides have been quite successful in the control of insects because they can quickly immobilize (knockdown) and kill the target pest. However, potential resistance problems exist, especially in insects previously selected by DDT and cross-resistant to pyrethroids. (It has been indicated that the mechanism conferring cross-resistance relates to a target site insensitivity (kdr).) Work by Cochran (1987) illustrated the fact that certain strains of B. germanica can develop resistance to a pyrethroid insecticide in as few as six generations in the lab and probably two years in the field. Synergists do lower resistance to pyrethrins, yet as resistance extends to other pyrethroids it is expected that inhibition effectiveness will drop. It has been strongly suggested that control programs reserve the use of pyrethroids as alternatives or for use with other insecticides, instead of using them as the primary type of control.

c) Boric acid

Boron is a naturally-occurring element found in the earth's crust and background levels of it are found in the human blood stream. Boric acid, a derivative, is a safe and effective alternative to conventional insecticides which does not create the indoor air problems associated with insecticidal sprays. It is significantly less repellent than chlorpyrifos, dichlorvos, encapsulated diazinon, fenthion, malathion, propoxur, pyrethrins, and resmethrin. Its toxicity falls somewhere between that of aspirin and table salt. But most importantly, in all the years that it has been used, insects have not become resistant to its very basic mode of action.

The best boric acid compounds have an anti-caking ingredient to help keep the dust effective in damp areas and are electrically charged to improve adherence to the insect. An added safety feature of boric acid dusts is that they are blue or green in color with a bitter taste to discourage children and pets from ingesting it. Boric acid can be diluted and applied as a wash, although it is more effective as a non-volatile dust which can be applied around stoves, refrigerators, and ductwork, and in wall voids or hard-to-seal cracks. Cockroaches walk through the dust and pick it up on their legs, antennae, and body. The dust then penetrates the cuticle and acts as a mild contact insecticide. Grooming leads to ingestion, at which point the boric acid acts as a stomach poison.

In a study conducted by William E. Currie, a member of the IPM Unit at the U.S. Environmental Agency, it was found that boric acid was a better treatment for cockroaches than chlorpyrifos (Dursban^{R}). An aerosol formulation of boric acid was applied in cracks in one area of a school cafeteria and chlorpyrifos in another. Before application, Currie monitored the sites using sticky roach traps to estimate population sizes. From trapping data collected over a two year period, Currie found that one application of boric acid reduced the average trap catches from forty to three in three months. The single application of boric acid maintained this average for three years. Two applications and one retreatment with chlopyrifos were required to achieve similar results. Of the two treatments examined, boric acid was clearly the more cost-effective.

It has also been shown that boric acid plus 0.1 percent Dri-die is more effective at controlling the occurrence of German cockroaches during construction than boric acid alone, Dri-die alone, and boric acid plus 0.1 percent Cab-O-Sil (an anti-caking compound). Eighteen months after one application, only two cockroaches emerged by flushing with a pyrethrin spray (used as the monitoring tool). In contrast, untreated apartments averaged thirty-one cockroaches.

Although the advantages of boric acid are well illustrated, it is not as widely used as would be expected. Its major drawback is its lack of "quick kill" (somewhat of a tradeoff for its long-term effectiveness). Another disadvantage is that boric acid dusts can be absorbed through skin lesions and also inhaled, which necessitates following label precautions and wearing a dust mask to prevent inhalation. Also, some pest control operators find it too noticeable, difficult to properly apply, and not as profitable a service to offer as conventional insecticide treatment.

However, new advances in packaging and formulation are counteracting negative opinions. Early boric acid containers had poor applicators which caused the dust to form piles; piles cake and become ineffective since they are detected and avoided by cockroaches. Products by R-value of Georgia include built-in applicators for easy direction and application. R-Value has also introduced an aerosol formulation that is particularly useful in hard to reach areas. New packaging has lessened the need to handle the material and also made it less likely that the material will be stored in unmarked containers.

Boric acid, in the form of roach tablets, was the first pesticide registered in the United States. Today these tablets have found their place in IPM programs for use in very damp areas (they can even be glued on walls). A new bait station containing boric acid paste has been made by It Works, Inc. of Connecticut. The product is child-resistant and contains a humectant to draw moisture from the air and retain it, thereby increasing the product's life. The paste can even be bought in bulk and applied with a caulk gun or spatula.

To decrease application time, Parker Pest Control, Inc. of Oklahoma has developed a power duster P.E.S.T.® machine that provides even coverage of treated areas. It operates under an adjustable pressure and charges the dust to increase effectiveness. The machine can be bought by institutions for in-house use, or pest control operators can participate in a license agreement package including two machines, staff training, and participation in national service contracts. The machines have a life-time warranty. Continued service by pest control operators would be needed to retreat areas that are regularly mopped or disturbed, to monitor populations, and to communicate with residents about the program.

d) Insect growth regulators

(1) Exposure effects of hydroprene and fenoxycarb

It is known that insect growth regulators (IGR's) with juvenile hormone activity cause a number of reproductive, developmental, and morphogenetic effects against certain groups of insects. Advantages of IGR use include low mammalian toxicity, target pest specificity, and a mode of action which stands in sharp contrast to that of conventional insecticides (an important consideration given the developing resistance). The only insect growth regulator currently registered and sold for control of the German cockroach is the juvenile hormone analog hydroprene. This JHA juvenilizes and sterilizes adults which had been exposed to it as fifth stage nymphs. Fenoxycarb, another juvenile hormone analog, has similar effects and will soon be sold for German cockroach control. King and Bennett (1988) examined the developmental responses of different age classes of nymphs topically exposed to hydroprene and fenoxycarb.

Technical grade formulations of fenoxycarb (96.8 percent) and hydroprene (96 percent) were diluted in acetone and applied to the ventral abdomen of newly molted first-, second-, third-, fourth-, and fifth-stage nymphs. Three replicates, ten nymphs per age class, were treated with either 0.01, 0.1, 1.0, 10.0, or 100.0 micrograms of each JHA. (Smaller nymphs received doses that were actually twice those of older nymphs due to the difference in size.) Control nymphs were treated with acetone. After treatment, individuals were reared in separate containers and their development monitored.

The highest percentage of mortality (76-100 percent) occurred with the 100 and 10 microgram per microliter concentrations of fenoxycarb administered to nymphs of stages one through four. These percentages were significantly greater than those caused by hydroprene and acetone. The only hydroprene treatment that caused a mortality percentage greater than that of the controls was 100 micrograms per microliter applied to first stage nymphs. Apparently, more than this amount of hydroprene is required to affect all age classes of B. germanica.

The nymphs killed by fenoxycarb exposure between the first and fourth stage showed no signs of poisoning until the time when controls molted to the next stage. At that point, treated nymphs became excessively black and exhibited uncoordinated leg movements while on their backs. Mortality onset time was usually the same for all nymphs per age class regardless of the concentration used. Symptoms lasted for one to four days before the insects died. Most nymphs died with their cuticles intact which means that they were probably unable to undergo ecdysis. Nymphs exposed to fenoxycarb at the fifth stage lived for around forty-nine days after the final molt of the controls. A few emerged as adults, but they were unable to fully shed their old cuticle and eventually died. Researchers have theorized that excessive quantities of JHA's or juvenile hormones lead to ecdysone (molting hormone) deficiencies which prevent lysis of the old cuticle. Further investigation is needed to elucidate the mechanism behind this process.

Nymphs surviving exposure to 100 or 10 micrograms per microliter of fenoxycarb during their fifth stages were the only ones that exhibited significant developmental delays. Survivors took up to nine weeks longer than controls to become adults and were physically abnormal (e.g. twisted wings, improperly formed sensory organs, increased melanization). It can be concluded that fenoxycarb shows a greater lethal activity against B. germanica nymphs than hydroprene (probably due to differences in chemical structures). Fenoxycarb is therefore a promising control technique since it not only kills young nymphs but also sterilizes adults exposed as fifth-stage nymphs. Preliminary testing has shown that fenoxycarb can actually sterilize nymphs at a dose much lower than that required to kill younger nymphs (i.e. 13 micrograms per gram). Further testing should determine whether the amount of active ingredient found in commercial formulations is sufficient to kill as well as sterilize B. germanica.

(2) Treatment and retreatment effects using hydroprene

Bennett, Yonker, and Runstrom (1986) evaluated a long-term treatment and retreatment program of hydroprene against German cockroaches in multi-family housing units. Existing infestations were attributed to inadequate maintainence, general clutter, and poor sanitation. Before the treatments began, insect populations in the kitchens and bathrooms were visually sampled. Sticky traps were used to evaluate existing population structures and to determine the number of adults with twisted wings (hence, estimate the number of late-stage exposures).

Four treatment regimens were evaluated (initial/retreatment): 1.2 percent hydroprene / 1.2 percent hydroprene, 0.6 percent hydroprene / 0.6 percent hydroprene, 0.6 percent hydroprene / propetamphos + 0.6 percent hydroprene, 0.6 percent hydroprene / none. Retreatments were done after three months. A fifth treatment, used for comparison, was an initial application of prepetamphos followed by propetamphos (a conventional residual insecticide) retreatment. Four to six foggers were used per apartment. The release rate for the high and low concentrations were, repectively, 6.80 grams and 3.40 grams. The rate for propetamphos was 18.5-37.0 grams. Posttreatment sampling occurred at one, two, three, six, and twelve months.

For three months posttreatment, the propetamphos-only treatment gave population reductions like the four hydroprene treatments. But, at six months the 1.2 percent hydroprene fogger gave a higher population reduction than the propetamphos-only application. There was no statistical difference between the 1.2 percent and 0.6 percent fogger applications when the retreatment was with hydroprene, but the 1.2 percent fogger gave the highest and most consistent percent reductions over a twelve month period. (The 0.6 percent fogger dropped in effectiveness compared to the 1.2 percent fogger at the six month point.) Both 0.6 percent fogger treatments followed by hydroprene retreatment gave higher reductions than a single application of the 0.6 percent fogger. The greatest number of twisted wing adults were caught six months posttreatment.(These last two findings indicate that extended effectiveness is dependent on hydroprene retreatment at three months.)

An important finding in this experiment is that the population reduction achieved by propetamphos plus the 1.2 percent fogger was greater than two applications of propetamphos. It is therefore more beneficial to reapply the low-toxicity IGR than to reapply the conventional insecticide. The potential for decreasing use of a residual insecticide of moderate toxicity without diminishing control clearly indicates a place for hydroprene in IPM programs. Similar benefits were observed by Ogg and Gold (1988) using chlorpyrifos and fenoxycarb. Chlorpyrifos was found to decrease the cockroach population significantly less than three different levels of chlorpyrifos-fenoxycarb combinations. The improved activity of the chlorpyrifos-fenoxycarb combination opposed to the use of chlorpyrifos alone was attributed to the IGR effects induced by fenoxycarb. The success of fenoxycarb is dependent on the ability of the insecticide to maintain cockroach populations at relatively low initial levels, until the IGR effects can be exerted on the population. Further tests are necessary to determine the most suitable insecticides for this purpose.

(3) Effects of fenoxycarb on technicians

It has been reported that the LD_{50} of fenoxycarb to rats is greater than 10,000 mg/kg body weight orally, over 20,000 mg/kg dermally, and over 480 mg/kg inhaled (four hour exposure). The following study by Ogg and Gold (1988) is pertinent to our discussion since was designed to measure the exposure of technicians and the contamination of residences when three concentrations of fenoxycarb, tank-mixed with chlorpyrifos, had been used for control of the German cockroach.

Two experienced technicians applied fenoxycarb in three sites in each of twenty homes. A 0.5 percent chlorpyrifos and 1 percent fenoxycarb mixture was used. In the first test, dermal exposure of the technicians was estimated. The technicians wore a one-piece polyester coverall with an open collar and short sleeves, an open-mesh cap, respirator, and neoprene gloves. Dermal exposure pads were placed on the outer clothing and all clothing beneath the coveralls (forearm pads were directly attached to the skin). Other pads were attached to the head, chest, back, thigh, and just above the ankle. The pads contained no material that would interfere with fenoxycarb detection.

After exposure, the pads were removed and subsequently analyzed in the laboratory. The total amount of fenoxycarb found on the pads was divided by the exposed area of the pad and the elapsed application time to give the rate of exposure (micrograms per square centimeter per hour). The workers washed their hands in a bag containing 150 ml of methanol (fenoxycarb is soluble in methanol). The total amount of fenoxycarb removed from the hands was divided by an estimate of the total area of both hands to give a figure for the rate of hand exposure. It was found that the neoprene gloves received 98.7 percent of the dermal exposure and that technician's hands should therefore be protected.

Respiratory exposure was also estimated through attachment of an air-sampling pump to each worker. The device consisted of a battery-powered air pump fitted with a glass sleeve that had a polyurethane foam plug to scrub fenoxycarb from the air. The air sampler was attached to a belt fastened around the lower back, with one end of a Tygon tube attached to the air sampler and the other to the inlet of the glass sleeve. The tube was attached over the shoulder and rested on the chest in such a way as to simulate the downward position of the human nostril. Data was expressed as micrograms fenoxycarb per liter of air. The amount of fenoxycarb acquired was divided by the application time and the pumping rate (respiratory rate was assumed to be 1,740 liters per hour). Average exposure was 0.33 micrograms per liter, a low value which suggests that exposure was minimal. However, no threshold limit value has been set for fenoxycarb by the American Conference of Governmental Industrial Hygienists (1984).

Environmental contamination was estimated by the surface wipe sampling method at three non-target sites in each residence. Sampling was done just prior to application, right after application, and one day, one week, and one month after. The sample surface was treated with methanol and scrubbed with gauze until dry. Exposed pads were treated as in the dermal exposure part of the study, with the total amount retrieved divided by the sampled surface area and the application time to give an estimate of the contamination rate. Fenoxycarb was detected only right after application. At all other times there was no evidence of the IGR (the reason for this "decrease" is unknown). Means were as follows (micrograms per square centimeter per hour): 0.32 (kitchen counter), 0.41 (kitchen floor), and 5.22 (bathtub).

The total dermal plus respiratory exposure was equal to 21.16 mg/hour for a technician wearing "full garb". The respiratory exposure was 1.565 mg/hour. It can generally be concluded from this study that under the stated conditions, the application of 1.0 fenoxycarb causes no significant risk to either the technician who mixed and applied the chemical or to the residents of the treated stucture. Normal work apparel including gloves appeared sufficient as a barrier to skin penetration. It is also advised that residents not be allowed into the residence during application and that exposure be reduced by ventilating treated areas.

e) Photodynamic dyes

It has been reported that American and Oriental cockroaches become moribund when they are exposed to light after internalizing rose bengal or erythrosin B (xanathene) dyes. Recently, Ballard, Vance, and Gold (1988) explored the light and dark reactions of the German cockroach and the brown-banded cockroach after being fed rose bengal and erythrosin B.

German cockroaches were used in the first phase of the experiment. Each dye was administered in a 1 percent sucrose solution and 5 x 10^3 M concentration to males, females, and nymphs kept in dark confinement chambers. Mortality was recorded at twenty-four hour intervals for 92.5 hours. At that point, lights were turned on and mortality readings were taken each half hour for the first hour and a half, then hourly for six hours.

In another test, adult male German cockroaches were given free access to the two dyes at these concentrations: 1 x 10^3 M, 3 x 10^3 M, or 5 x 10^3 M in 1 percent sucrose. Mortality was recorded daily for six days. Ten survivors were removed from each container, anesthetized, weighed in a dimly lit room, and returned to their container. One control group was given the dyes but was not weighed to indicate the mortality associated with handling and exposure to dim light. In the other control the subjects were given 1 percent sucrose but no dye, and then put through the weighing procedure. This provided information on mortality due to intake of the dye and also provided baseline data on population weight for untreated cockroaches.

It was found that all the subjects were affected by the dyes when administered at the initial concentration, but mortality associated with the light-independent reaction was greater for adults than nymphs. The erythrosin dye was more toxic to all the subjects during the dark phase of the experiment and for the first 2.5 hours of light exposure. Male and female mortality increased for two hours after the onset of light, with nymphs responding more slowly to the light-dependent effects of the dye than adults did. There was significant light-independent weight loss among cockroaches given rose bengal at 3 x 10^{3} M and erythrosin B at 5 x 10^{3} M.

Brown-banded cockroach nymphs were used in the second phase of the experiment. Dyes, in the above trio of concentrations, were administered to the nymphs which were confined in glass bottles. One control population was given the sucrose solution alone as food. Mortality was assessed at twenty-four hour intervals for 144 hours, after which time the subjects were exposed to light. Mortality was then assessed every half-hour until 146.5 hours had passed. The other control was given the dyes but kept in the dark for 146.5 hours. Mortality results for the brown-banded nymphs were consistent with those seen for the same concentrations in German cockroaches. Over time, mortality was greater with erythrosin B than with rose bengal during the light-independent reactions (for all concentrations). Light-dependent effects increased mortality during the 2.5 hours of light exposure.

It was concluded that both photodynamic dyes cause mortality in German and brown-banded cockroaches and that light-independent weight loss due to dye exposure occurred in male German cockroaches. Light-dependent mortality was observed for both species of cockroach. The use of these dyes as control measures has been investigated under field conditions using flies (Musca spp.) and fire ants (Solenopsis germinata (S.)). The feasibility of using these dyes needs to be pursued, particularly since erythrosin B has an acute oral LD_{50} in rats of over 7,000 mg/kg.

f) Anacardic acid

Dr. Isao Kubo, a chemist at the University of California at Berkeley, has isolated a chemical (anacardic acid) from root bark of the African Msimbwi tree which has potential use for the control of cockroaches. In the early 1980's, insect physiologists at Berkley found that injecting E2 and F2 prostaglandins (chemical messengers) into crickets (taxonomically similar to cockroaches) caused them to lay eggs. This chemical was believed to be passed by the male to the female during mating to stimulate egg-laying. When asked to look for prostaglandin presence in male crickets, Kubo could not find any even though the biochemical was easily isolated in fertilized females. It was then suspected that the males injected into the females not the biochemical itself, but something that caused its manufacture in the females. Prostaglandin synthetase, an enzyme present in male crickets, was found to initiate and accelerate creation of prostaglandins from a precursor in the female. From these findings, it was postulated that a form of insect control could be worked out if the enzyme in the males might somehow be suppressed, consequently preventing egg-laying in the female.

Kubo recalled that, in Africa, loads of the cashew fruit tree are dumped into ponds to inhibit mosquito larvae. Also, that the root bark of the Msimbwi tree can be used to induce abortion. The active ingredient in both these cases was found to be anacardic acid. Research was continued with the crickets, witheach sex being injected with the substance. In male spermatocytes a decrease in synthetase content resulted; in fertilized female eggs there was a reduction in prostaglandin content. Kubo found that without a sufficient quantity of prostaglandin to stimulate the smooth muscles of the female's egg-laying apparatus, eggs could not be passed. Interpretation of these findings in light of control mechanisms spells potential use of anacardic acid in a bait, or in the form of a spray or powder that can be absorbed through the exoskeleton. Kubo disclaims commercial potential at this time but is planning large-scale experimental trials with the chemical.

3. Biological control of cockroaches
   a) Use of a hymenopterous oothecal parasitoid

Cockroach natural enemies include other insects, arachnids, nematodes, and vertebrates, but possibly the most important are the hymenopterous oothecal parasitoids. Since these organisms are small and actively search for hosts they represent a promising mechanism of control for urban pests.

Coler, Driesche, and Elkinton (1984) reported the effect of the oothecal parasitoid Comperia merceti (Compere) on a population of brownbanded cockroaches (S. longipalpa (F.)). An existing cockroach infestation was repeatedly sampled over the course of three years using baited glass jar traps. About a year into the sampling period, the cockroach population was artificially stimulated by supplemental feeding. This "outbreak" was used to evaluate the effect of the parasitoid. After each sampling period, the traps were examined and the specimens divided into five categories: adult males, adult females, and three classes of nymphs. "Catch" was the number of each category caught per trap per day. Trapped cockroaches were released back into the infested room from which they were captured.

Parasitoid activity in the infested room was measured by exposure of cockroach oothecae which had been provided by a laboratory-reared colony of brownbanded cockroaches. The oothecae had been laid on paper toweling and were about three and a half days old. Strips were cut from this toweling and hung in locations in the infested room where the invading cockroaches had previously deposited oothecae. After one week of exposure, the eggs were taken back to the laboratory and raised individually under atmospherically controlled conditions until all parasitoids and cockroaches emerged.

Results, based on the number of parasitoids emerging per ootheca or the proportion of oothecae attacked, indicated that there were no statistically significant differences in the parasitoid's preference for oothecae of different ages. (Implied is that an appropriately aged group of oothecae had been used as subjects; further, that it is possible to view the entire oothecal stage as somewhat susceptible to attack.) Parasitism was minimal when cockroach densities were low and did not increase until after the cockroach population was stimulated. Later in the study, the degree of parasitism dropped sharply before leveling out for the duration of the study. The resultant decrease in cockroach density (and corresponding drop in trap catch) paralleled the increase in parasitism and manifest itself first at the nymph level then at the adult level. Initially, the youngest class of cockroaches dominated. With time, the age structure became inverted as is characteristic of a declining population whose nymph number is depressed. Later, surviving nymphs came to represent the adult segment of the population. The initial population structure was eventually regained but all stages were present at a lower density.

This study clearly indicated the ability of C. merceti to suppress populations of S. longipalpa (L.). This conclusion was supported by the inverse relationship between the degree of parasitism and the cockroach population, and also by the changes in the age structure of the cockroach population. However, the directly proportional relationship between parasitism and oothecal density suggests that the effectiveness of the parasitoid may be limited to only high-density host populations (unless a mass release of parasioids is used against a cockroach population of low density). The researchers acknowledged difficulties associated with rearing and supplying live organisms (parasitoids) but also stated that some pesticide-sensitive areas (zoos, pet shops, laboratories) may find this sort of biological control preferable to the use of conventional insecticides.

b) Potential use of fungi

Although over 750 species of fungi have been described as entomopathogenic, less than ten have been used as biological agents of control. Twenty-five species of Herpomyces are host-specific parasites of the cockroach cuticle but none have deleterious effects on the host. Few intestinal fungal parasites exist and reports on pathogenic fungi of cockroaches are not available.

However, one fugal infection occurring in a laboratory colony of B. germanica has been studied by Archbold and others (1986). A reliable source of the infection was maintained by transferring uninfected cockroaches from a control colony to the infected colony. Live infected cockroaches were collected periodically and categorized according to instar, behavior, activity, and general appearance. Early signs of the disease were hard to distinguish, although later symptoms included sluggishness, premature adult death, and predominance of nymphs. The best external symptom was brittle and curled antennae. Internal presence of infection was indicated by yeast cell presence in the hemolymph. Infected individuals usually died upright, with their legs stiffened in a paralytic posture suggestive of nerve or muscle dysfunction. Retarded movement and loss of coordination often preceded death. Additional stresses such as carbon dioxide, anesthesia, food and water deprivation, and insecticidal treatment caused increased mortality.

In insects, hemolymph circulates by tidal flow through muscle contraction, pumping of the dorsal aorta, and through pumps located at the base of the legs and antennae. Inadequate blood circulation due to the number of yeast cells in the hemolymph could have resulted in poor nutrient supplies reaching the antennae and other appendages. The pathology of the disease is associated with a high number of yeast cells, and high titers are associated with the appearance of the characteristics mentioned above. The symptoms were followed by a decrease in activity and, within thirty days post infection, death.

Verrett and others (1987) noted a similar infection in a laboratory colony of American cockroaches (P. americanum). The researchers described in detail certain physical changes and identified the infecting organism as a form of Candida. Damage done by the yeast involved the host granulocytes (one of the two main types of hemocyte in the American cockroach). Nuclei of infected cells were found to be indented and nuclear membranes raised near the yeast cell. Host cell nucleoplasm had disintegrated and little cytoplasm was present. Damage to the cockroach hemocyte is thought to be due to a toxin, a potentially potent agent for penetrating the insect and digesting its tissue or hemolymph. The action of the enzyme (canditoxin) in C. albicans (not the species isolated in this study) is believed to inactivate proteins by interfering with vital physiological functions. The mechanism may involve a slowing or cessation of the flow of transmitter substances in motor neurons.

Cockroaches mount an immune response by either phagocytosing or encapsulating yeast cells. Encapsulation occurs when hemocytes encounter "non-self" surface characteristics and release intracellular granules which have a chemokinetic effect on neighboring hemocytes. Resultant adhesion of the cells forms the first layer of the capsule. Other cells are similarly recruited which causes an increase in layer formation.

Use of the biological agent found in P. americanum as a control is not feasible at this time, but it is possible that a physiologically different strain could be developed. However, because sibling species are human pathogens, development would have to procede with great care. Use of the organism even in baits may still subject humans to the disease agent through food exposed to cockroach droppings. These studies did serve to elucidate the mechanism behind cockroach immunity (an important advance when this and other yeast infections are considered) and to advance the study of a potentially viable method of cockroach control.

4. Physical control of cockroaches
a) Household measures

Harborages can be washed, vacuumed, or steam-cleaned to eliminate egg cases, fecal material, and accumulated bits of food. Vacuumings should be burned, deeply buried, placed in sealed containers, or composted after the infested area is disinfected with ammonia. Outdoor populations can be reduced by moving debris from around the building. In general, physical methods of combat (including swatting or stomping on adults) are relatively unimportant in a cockroach management program unless they are directed at trespassers in uninfested areas.

b) Ultrasound

The use of ultrasound devices to control pests was widely publicized in the early 1980's, but research on its use for agricultural and urban purposes has been limited. In response to the public's continuing requests for information and because previous laboratory tests have detailed responses to pure tones emitted by non-commercial devices, Ballard, Gold, and Decker (1984) investigated the effectiveness of a commercial frequency-modulated ultrasound device (Pest Guard).

The device required a 120 V AC, 60 Hz power source and supposedly swept through a range of 30-65 kHz. Eight plywood test cubes were caulked and white-washed to maximize sound refection and were fitted with the device in an upper corner. The cubes also had a pitfall trap opposite the device to catch moving cockroaches. A significant increase in movement (hence trap catch) occurred in cubes with active devices, but habituation occurred in six to seven days. No significant difference in daily mortality existed between control and active-device cubes (this was consistent with the manufacturer's claim that the device did not actually kill the insects). In essence, the cockroaches continued to exist in the structure even though a decrease in their visibility may have occurred in "treated" areas. The advantage to simply increasing cockroach movement within a structure is somewhat difficult to see.

Koehler, Patterson, and Webb (1986) evaluated the ultrasound produced by nine different devices in an effort to determine their ability to control German cockroaches. Using two unfurnished rooms connected by a corridor, the researchers set up an acoustic gradient which permitted the cockroaches to voluntarily enter or exit "noisy" areas. While it was found that almost all the devices did put out alternating high frequency sounds, placement of furniture in the treatment room significantly reduced the sound pressure level. There was no predominant movement of the cockroaches to untreated rooms. In fact, it was found that cockroaches were just as likely to enter treated as well as untreated rooms. Monthly trap catches showed that the German cockroach population had not significantly decreased through use of the devices. In fact, twenty-four hours after some devices had been returned to the lab, eight nymphs emerged. The cockroaches were obviously using the devices as a harborage and were clearly not repelled by them. Manufacturer claims were generally considered unfounded given the observed lack of repellency and the reduction in ultrasound intensity caused by the presence of furniture.

c) Zap Trap™

A relatively new trap, manufactured by Bi-Pro Industries, Inc. of California, contains a lure and an electrified grid that jolts the attracted cockroaches onto a disposable sticky surface. The device can hold up to three thousand cockroaches. The lure (a secret formula probably containing a female sex pheromone) attracts all major cockroach species. Lures are replaced every one to two months and cost about six dollars. A powerful glue on the trays can hold even larger cockroaches like the American and smokeybrown. The devices generally require an electric outlet but some are battery-powered.

The trap can be used alone in less densely infested or localized areas, or when a client prefers not to use conventional insecticides. Ed Brown of International Roach Busters of Massachusetts combines these traps with boric acid treatments. The traps catch sluggish cockroaches and essentially buy time for the slower-acting boric acid.

B. Mulligan of Simon Fraser University in Vancouver, British Columbia has shown in field and lab tests that cockroaches are more attracted to Zap Trap™ than conventional traps without lures. This attraction aspect, along with the fact that the trap is effective over a 2,500 square foot area suggests that cockroaches may be lured from up to 30 feet away. The trap is particularly useful in wet areas where boric acid cannot be applied. Unfortunately, the trap costs over three hundred dollars; some pest control operators offer lease-buy options.

5. The Asian cockroach: new control problem

The Asian cockroach Blattella asahinai, a recent arrival in Tampa, Florida, has proceeded to take up residence for six hundred miles around. Infestations of 90,000 to 165,000 per acre are common. Compared to the German cockroach, the Asian cockroach prefers lit areas (e.g. light-colored exteriors, turned-on television sets) and also flies. Richard Brenner, an entomologist at the USDA Agricultural Research Service in Gainesville, Florida, says that Asian cockroaches follow you from room to room until the last light is turned off, at which point they head for moist areas such as damp towels. Given their range in Asia, these cockroaches could exist as far north as Maryland on the east coast and as far as Washington on the west coast. In regards to control, the USDA has no jurisdiction since the Asian cockroach is not a plant pest. The Florida Department of Health also waives responsibility since no valid cases of endangerment have been reported.

II. Wood-boring beetles

A. Identification of the problem

Wood-boring beetles, when considering the damage they cause in the United States, are next in importance to wood-rotting fungi, termites, and carpenter ants. An estimate for the annual loss due to repairs and wood-replacement caused by lyctid beetles is several million dollars. Three main factors have contributed to this species' pestiferous habits. One is the increase in demand for imported hardwoods. The tropical origin of some of these woods permits lyctid activity year-round, and the tropical woods themselves (e.g. banak, obeche, lauan/meranti) have attractively large pores and high starch content. Often, unprotected wood must be stored in the open due to shipping and processing delays. The second factor relates to the difficulty of recognizing infestations. Eggs are small and deposited in the wood, and adults may not emerge for about a year. Damage may not be apparent for a long time. The third factor concerns cargo containerization, a practice which restricts inspections at entry ports. Since an infestation may be considered by APHIS (USDA Animal and Public Health Inspection Service) to be impossible to quarantine, infested materials may be allowed to enter our ports. Some beetles can cause extensive damage, but identifying the species, determining whether or not larvae are present, and evaluating the extent of the damage are the most sensible steps to follow before initiating treatment.

B. Biology of wood-boring beetles

1. Introduction

The first step in controlling wood-boring beetles is to identify the infesting species. Two general categories can be constructed: those that can reinfest wood and cause extensive damage, and those that cannot reinfest wood and cause damage only for the existing generation. There are three important families of reinfesting beetles: true powderpost beetles of the family Lyctidae, furniture and deathwatch beetles of the family Anobiidae, and the old house borers, a member of the family Cerambycidae. Infestations of other beetles are often over by the time they are detected. "Non-reinfesters" generally enter the house within wooden objects or lumber used in construction. When adults emerge from the wood, they die and infestation ceases.

Emergences may occur for a period of weeks or months but should not be mistaken for reinfestation.

2. Lyctid beetles

Lyctid beetles are the most widespread reinfesters in the United States, readily attacking furniture and structural wood components. Under natural conditions, lyctids overwinter in the larval stage. When spring comes, larvae bore closer to the surface of the wood, and make a cocoon-like structure or pupa. Two to three days later, after emerging as adults and mating, the females lay their eggs in the surface of the wood (namely the sapwood of hardwoods with large pores for depositing eggs). The most susceptible woods are hardwoods such as oak, hickory, and ash. Less susceptible species include walnut, pecan, poplar, sweetgum, and wild cherry. Wood species that are "immune" include certain softwoods (cedar, fir, pine, and spruce) and certain hardwoods (basswood, beech, and birch). A wood moisture content (WMC) between 8 and 32 percent is required for oviposition. Most activity is associated with 10-20 percent WMC which is typical of that found in many buildings.

Females lay an average of twenty to fifty eggs in exposed tree parts and milled lumber. At first, hatched larvae bore straight tunnels into the wood, but later the larvae paths criss-cross and become irregular. Flour-like frass can be found in the tunnels. Larvae emerge from the wood through circular exit holes 1/32-1/16 inch in diameter the following spring. Adults are 1/8 to 5/16 inches long, somewhat flattened, and light brown to black in color. Generally, life cycles are completed in nine to twelve months, but development can be hastened if temperature and wood starch content are favorable. With a starch content of 0.3 percent, a temperature between seventy and ninety degrees Fahrenheit, and humidity between 70-90 percent, life cycles can run between three and ten months. If these variables are all low, development can take as long as four years. Larvae grow fastest when the WMC is 14-16 percent.

Larvae cannot digest cellulose. Attack is solely to sequester starch contained in the plant material. Prior to egg-laying, females "taste-test" the wood to determine if it has a suitable starch content for the larvae. Eggs will not be laid where the starch content is below 3 percent. Wood recently dried through a kiln-drying (not air-drying) process is preferred for its higher starch content. (Old wood does not have a high starch content.)

3. Anobiid beetles

In general, the deathwatch and furniture beetles of the United States require more moisture than lyctids do. Hence, they are more problematic in coastal areas, unheated buildings, and where humidity is high. Contrary to what is implied by their common names, these beetles find furniture too dry to infest.

Some anobiids will attack hardwoods and softwoods, old or new. Sapwood is their basic food and they have the ability to digest cellulose due to the presence of yeast cells in their digestive system. Anobiids live on bark-free scars of trees or dead limbs, but are found in the house in humid crawl spaces.

Females use small cracks and crevices in the wood for egg-laying. When the larvae emerge from the eggs, they bore a little ways into the wood, then make a sharp ninety degree turn, proceeding in the direction of the woodgrain. As the larvae grow, so do their tunnels, becoming packed with fecal material (a fine powder with conspicuous elongated pellets). Eventually the tunnels intersect, and the wood disintegrates into a mass of fragments. Two to three years are needed for complete larval development, but dry conditions encountered during this time can draw out the development process and possibly kill the young. In the spring, larvae widen part of one tunnel and bore an exit hole (circular, 1/16-1/8 inch). Mates are sought and the cycle begins again. Adults are 1/16 to 3/8 inch long with their heads hidden beneath a hood-like thorax. Many females lay their eggs in the wood from which they have just emerged.

4. Cerambycids (the old house borer)

Old house borers (Hylotrupes bajulus) do not need a bark covering on the wood that they infest. Females lay their eggs in crevices in the wood and emergent larvae often wander about until they find a suitable place to bore into the wood. Once inside, they remain near the surface, gradually going deeper as they grow. Old house borers do not attack heartwood. The larval stage can be completed in two to three years but can take as long as fifteen if the wood is very dry (as in attics). Tunneling in dry wood proceeds slowly, and the tunnels are characteristically marked by ring-like striations and tightly packed coarse frass. Unlike the anobiids, old house borers do not need yeast in their guts to digest cellulose. Adults, 1/3 to 2 inches in length, remain in the tunnels for some time prior to emergence and mating in mid-to-late summer. Exit holes are oval or round and species-dependent in size. Because emergence may be staggerd over a period of years, these beetles often appear to be doing more damage at a faster rate than is really the case. Temperature has been the primary factor limiting their spread in the United States.

5. Non-reinfesters

Non-reinfesters are responsible for attacking weakened forest trees. Larvae (grubs) remain in these trees through milling and emerge later as adults. Some beetles lay eggs within the bark of freshly-cut trees. If the wood is not cured, or cured improperly, larvae-infested wood can be used in homes, with emergence occurring after construction. Beetles may come through ceiling beams, subflooring, hardwood floors, and wall plaster.

Non-reinfesting beetles include flathead borers (Buprestidae), most roundheaded borers (Cerambycidae), and bark and timber beetles (Scolytidae). Reinfestation is impossible for these beetles unless bark, the cambium layer, or the living sour sap xylem of the wood is available for egg-laying. Since none of these parts are found within structures, non-reinfesters are unable to survive and die without laying eggs.

C. Detection

Aside from beetle presence, infestations can be detected by the appearance of exit holes and fecal pellets. These two characteristics are helpful in identifying the invading species. The following considerations should be made: the size and shape of the exit holes, whether the damage is to hardwood or softwood, whether the wood is old or new (all of the beetles discussed here will infest new wood, only three of the reinfesting type will attack old wood), and the type of frass found in the tunnels. Identifications can be confirmed by a Cooperative Extension Service entomologist.

Inspections for wood-boring beetles should be performed yearly, in conjunction with the inspection for termites, keeping in mind all the "hot spots" listed in our discussion of termite detection. Things to look for include entrance and exit holes, sawdust or wood fragments, and weakened, hollow-sounding wood. It should be emphasized that discovery of these things does not necessarily imply that an active infestation is present. "Used" wood may not be suitable for later generations, and environmental conditions may inhibit survival. The presence of fresh frass and living beetles should be used to determine activity. In some species (e.g. old house borers), chewing can be heard inside the wood. Assessment of the damage caused by reinfesting beetles can be difficult to determine, possibly not until damaged wood has been removed.

As in detection of termites and (potentially) carpenter ants, dogs can also be trained to increase the accuracy of detecting infestations by wood-boring beetles. Their keen sense of smell and hearing as well as their size enable them to detect infestations overlooked by pest control operators.

D. Prevention

1. Inspection

There are six main ways to prevent the occurence of wood-boring beetles in the home. The first involves inspection of wood and wooden items before they enter the house. Small holes, sawdust, and tiny wood fragments are key signs of a potential problem. Antiques and imported wooden craft items are likely culprits. Exposing the items to extreme heat or cold will basically solve the problem.

2. Sealing wood surfaces

Sanding and coating susceptible woods is a preventative technique that works well against lyctids. Varnish, shellac, and paint fill pores in the wood, hence eliminate desirable egg-laying sites for females. The most susceptible locations are unpainted storage containers or other wood items around the house. If such items are made of a softwood such as pine, infestations are unlikely since lyctids prefer large-pored hardwoods such as oak, ash, hickory, mahogany, and bamboo. The furniture beetle also avoids sealed surfaces.

3. Reducing available moisture

Adequate ventilation and drainage around a building tend to reduce the moisture content of the stucture's wooden members, and in so doing decreases the chance of beetles finding suitable wood sources. Particular attention should be paid to this aspect of prevention in areas where humidity is high and where winters are warm. Homes that are centrally-heated and remain so for extended periods of time are less susceptible than other residences to attack by beetles. Vacation homes are often sites of damage because heating periods are not prolonged and because tight-sealing permits high levels of moisture in the wood.

4. Storing firewood outdoors until it is needed

Firewood brought into the home may already be infested with powderpost beetles. It is suggested that piles of firewood be kept outdoors, the largest the farthest away, and smaller ones nearer the home. Wood scraps should not be allowed to accumualte around the house and should be burned regularly.

5. Debarking stored logs

Additional protection of stored wood is afforded when the wood is debarked. Some beetles need bark to start tunneling and egg-laying. (Elm owners might already be aware that debarking elm before storage prevents infestations by the beetles that cause Dutch Elm Disease.)

6. Using kiln- or air-dried lumber

Using kiln- or air-dried lumber seems to be the best and least expensive preventative measure that can be taken. Drying processes kill many sorts of beetles, including all stages of lyctids. It should be noted that drying schedules are based on the thickness of the largest piece of lumber in the given load, not on initial wood moisture content. Kiln sterilization of finished products may damage glue joints, and it is important to remember that this process does not necessarily prevent reinfestation.

7. Using boron compounds

Another preventative measure being studied is the treatment of unseasoned (undried) wood by dip-diffusion with boron compounds such as TIM-BOR[R] (disodium octaborate tetrahydrate), AM-BOR-S[R] (ammonium pentaborate-sodium sulfate), and AM-BOR-P[R] (ammonium pentaborate-sodium phosphate. The dip-diffusion process must be performed at the mill since it depends on the wood's own moisture content to facilitate diffusion of the preservative into the wood. Sapwood should be completely penetrated after dipping and no further treatment should be required, even after the wood is processed.

In a series of experiments conducted through the USDA Forest Service, Southern Forest Experiment Station, investigators used banak wood in a dip-diffusion process aimed at preventing lyctid beetle infestation. Banak wood refers to about forty Central and South American species in the genus Virola. The wood is imported from native regions and used in the United States for millwork, moldings, and picture frames. Slow water transport of logs and other hold-ups between felling and delivery to markets in the States often leads to degradation of the wood by ambrosia beetles and fungi. But, more important to United States consumers, processing delays also permit lyctid beetle establishment and spread through non-infested wood or newly-manufactured products. Products can be widely distributed during the year or more before exit holes of these beetles are seen, paving the way for complicated lawsuits and sundered business relations.

The researchers have determined the dip-time, solution temperature, and diffusion storage period that provideds the best dip-diffusion treatment. They have also found that loading (the amount of borate on wood available for diffusion after dipping) is affected by wood surface characteristics, dip time, solution temperature, concentration, and agitation (to keep the borates suspended). Wood surface characteristics and wood moisture are probably the primary variables since high borate concentrations can compensate for short immersion times. Factors found to affect the rate of diffusion include the wood species, wood density and thickness, ambient temperature and relative humidity, and length and manner of storage.

Other researchers have found that boron content in the center of treated boards doubles with a rise in ambient temperature from forty-five to sixty-five degrees Fahrenheit. Diffusion processes conducted in tropical regions should therefore proceed at a faster rate due to high relative humidity which maintains the moisture content in freshly-cut wood. It has also been found that the diffusion rate is not greatly affected by a 60 percent WMC, but that the diffusion time nearly doubles when the moisture content is reduced to 40 percent.

In commercial treatments, loosely-packed, partially stickered packets of freshly-sawn wood are immersed for approximately one minute in a 25 percent boric acid equivalent solution of polyborate and maintained at 130 degrees Fahrenheit by steam heat. Dipped boards are then stacked with stickers for seven days under a protective roof to allow the borate to diffuse into the wood. About 1.6 percent sodium pentachlorophenate can be used in the solution to prevent mold growth during the diffusion period. (pre-planing the wood before making wood products removes the mold growth inhibitor). An estimated thirty-nine pounds of polyborate can be used per thousand board feet, at a chemical cost of two cents per board foot (1985 prices).

Results obtained from boron treatments indicate that they afford protection against L. brunneus (Stephens), the eastern subterranean termite R. flavipes (Kollar), and the brown-rot decay fungus G. trabeum. Although bacterial symbionts have not been found in L. brunneus, they have been found in L. linearis Goeze and it is believed that boron kills lyctid larvae and termites by eliminating their intestinal digestive symbionts. Wood containing over 0.3 percent BAE (boric acid equivalent) of sodium borate is protected from R. flavipes (Kollar) and wood containing over 0.5 percent BAE is protected from G. trabeum. An undefined level less than 0.2 percent BAE is required to protect banak from L. brunneus. Treatments do not protect against mold fungi or soft-rot decay fungi.

The dip-diffusion process is appealing since boron-treated wood is not hazardous to its users and because treatment quality can easily be monitored by color-testing and hydrometer readings of the treatment solution. One man using a forklift can treat a days production in several hours. Dip-diffusion with boron compounds is a more cost-effective process than fumigation and replacement of damaged areas, and is also less expensive than pentachlorophenol and mineral spirit treatments used for moldings. Although boron salts are known to make wood brittle, one lumber company has reported no problems in shaping the moldings that they maufacture. It is also possible that treated scraps can be used in particle board. A bonus of the procedure is that it increases resistance to combustion. Less environmentally-sensitive alternatives to sodium pentachlorophenate are being investigated for use in the treatment solution. The major drawback of the process is that treated wood must be protected from leaching either by using it above-ground and protected by a roof or by finishing the wood with paint or a water-repellent.

E. Control

1. Chemical controls

a) Fumigation

Fumigation is the most common type of chemical control of wood-boring beetles. It involves draping an infested structure with a plastic sheet and using the highly toxic gas methyl bromide to impregnate the wood. Residents must vacate the premises for two to three so that the fumigant can sufficiently dissipate. Fumigating limited areas has not proven terribly successful. As stated previously, fumigation is an undesirable alternative due to its high cost, use of highly toxic chemicals, and temporary benefit. Although sulfuryl fluoride is also used as a fumigant, it is not effective at killing the eggs of lyctids. To compensate for this, the material is often used at a high dosage and at an added expense.

Chlorpyrifos is commonly used for spot-treatments of infested wood. It acts against adults that need to chew their way out of the wood and against larvae that emerge from the eggs laid on it. Chorpyrifos capitalizes on the fact that many wood-borers lay their eggs on the same wood that they emerged from. Surface spraying with lindane was once widespread, but it is no longer used. Some operators have experimented with injecting insecticides into infested wood. Because this treatment is costly, not thorough, and its results rather unpredictable, it is not recommended. Using pressure-treated lumber when replacing wood is an alternative, particularly for areas that are continually wet.

b) Pyrethrum

TriDie™ is a dust combination of a silica aerogel and pyrethrum that can be applied into and around exit holes of reinfesting beetles. The mixture can also be blown into wall voids, attics, and crawl spaces. Beetles are first killed by the pyrethrum, but when this ingredient has dissipated, the silica gel takes over as a residual insecticide that can kill beetles which emerge later by abrading their protective covering and prompting dehydration. Torpedo™ is another product, considerably less toxic than methyl bromide, which has permethrin as its active ingredient. A 0.1 percent solution has been shown to be as effective at controlling <u>L. brunneus</u> as lindane and chlordane, and the organophosphate fenitrothion. Synthetic pyrethroids are known to reduce egg-laying without killing adults and are also known to have a repellent effect (a technique which would prevent reinfestation). Spot treatment are a practical solution to the risks associated with fumigation.

2. Physical controls

a) Coating exterior surfaces

Beetle infestations can be physically controlled by replacing damaged wood, altering moisture and temperature levels around wooden structural members, and by treatment with the Electrogun™. Frequently, the best solution for beetle infestation is removal of damaged wood, since many of the wood-boring beetles do not reinfest the wood after they have emerged. However, reinfesters should be deterred by painting and varnishing exterior surfaces and by following the preventative measures outlined above.

b) Temperature and humidity variation.

Deathwatch beetles and old house borers are very susceptible to heat, changes in temperature, and lack of moisture. The deathwatch beetle Anobium puctatum, found in both Europe and the United States, can only enter wood that has already been partailly predigested by fungi. Laboratory studies have indicated that the old house borer does not do well when temperature and humidity fluctuate. Wood blocks containing larvae were placed in the attic, basement, and laboratory areas of a building in Virginia. Growth was inhibited in the attic when temperatures reached seventy-five degrees Fahrenheit and relative humidity as between 66 and 86 percent. In the laboratory, it was found that the larvae did best at eighty-six degrees Farenheit and about 82 percent relative humidity. The potential for using temperature and humidity changes as a form of control has been discussed under termite and carpenter ant control. Vapor barriers, ventilation, and central heating may even preclude the use of more elaborate physical methods of control.

c) Electrogun™

Use of the Electrogun™, explained in previous sections, is also effective at eliminating infestations of wood-boring beetles. Because the device leaves no harmful residues, is safe for the operator to use, and presents no hazard to the occupants, this technique is easily incorporated into least-toxic management programs. It is particularly suited to areas in which infested wood members (e.g. paneling) cannot be removed or replaced.

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RELATED ADVANCES: BACULOVIRUSES AND THE NEEM TREE

I. Baculovirus and the viral enhancing factor

II. Neem: a new frontier

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I. Baculovirus and the viral enhancing factor

Recently, attention has focused on the use of viruses as a form of pest control and it is possible that a suitable indoor application may eventually be found. Five hundred species of baculovirus are able to infect specific lepidopteran species. However, they do not act against mammals, plants, or other insects. When a baculovirus enters the larval host it quickly replicates, bloating the host with billions of virus particles each wrapped in a protective protein coat. The commercial usefulness of this type of infection is that these viruses can be genetically manipulated to cause the manufacture of certain "desired" protein products. For example, removal of the coat-protein gene from the viral DNA and attachment of its promoter to a chosen gene causes larval cells that possess the altered virus to produce large quantities of the "new" gene's product.

When a caterpillar feeds on a leaf and ingests a baculovirus, the alkalinity of the insect's stomach dissolves the virus's protein coat, allowing it to traverse the stomach wall and enter mid-gut cells. Within about ten hours, the viruses have replicated and filled these cells. In another two hours, infection production is at a maximum. After twenty-four hours the baculoviruses have again become packaged in their coats. The replication and packaging processes continue for approximately five days, at which time an infected caterpillar may be seen hanging from its perch, distended with virus particles that represent half its volume. When the larva dies and decomposes, the encased viruses are released. Protected from dessication and ultraviolet light by their protein coats, the viruses can remain on foliage for up to ten years.

While the baculovirus is a newcomer to genetic engineering, it has long been recognized as a natural insecticide. For example, it has been noted that sudden drops in populations of gypsy moths are often due to baculovirus epidemics. The EPA has approved use of four unaltered baculoviruses for control of the gypsy moth, cotton bollworm, European pine sawfly, and Douglas-fir tussock moth. Alan Wood and Anthony M. Shelton, virologists at Boyce Thompson Institute for Plant Research at Cornell University in Ithaca, New York, have created a baculovirus which persists in the environment for only a few days and is hence environmentally safe. The researchers stripped the baculovirus Autographa californica of its polyhedrin coat by deleting the gene that codes for it. The "naked" baculovirus was then mixed with a wild-type strain. Through a process called co-occlusion the wild-type viruses manufactured enough polyhedral coats to clothe the deficient particles. The resulting deficient strain was thus able to mimic the wild-type strain in appearance and enter its host (the cabbage-looper). The cycle ends at that point, since mimic descendents cannot produce protective coats and are degraded. Further testing of these short-lived baculoviruses has been pursued.

Robert R. Granados, also a virologist at Boyce Thompson, has discovered a protein in another cabbage-looper baculovirus (the Trichoplusia ni granulosis virus or TnGV). The coat protein has been called a viral enhancing factor (VEF) and is able to bore holes directly through the lining of the cabbage-looper's stomach, blasting a path for entry of the virus. Effects of the VEF have been found to be more dramatic in the TnGV than in A. californica. The VEF permits a 25- to 100-fold increase in the amount of kill compared to use of the virus alone.

There are four ways that the VEF gene could be used for pesticide purposes. First, it could be combined with a baculovirus known to attack a given crop-pest, then formulated into a spray and applied to susceptible crop plants. Second, the effectiveness of the protein might be enhanced through insertion of one or more copies of the gene coding for it into the TnGV. Third, new viral insecticides produced through genetic engineering of other baculoviruses can also be endowed with enhanced effectiveness through the protein's activity. Fourth, insertion of the VEF gene into the genome of certain crop plants could make the insects that feed on these plants more vulnerable to viruses as well as bacteria, fungi, and maybe chemical insecticides. The bacterium Bacillus thuringiensis, fatal to insects, has already been found effective when used in this manner and it is possible that even this bacterium could be improved through incorporation of the VEF gene. Although this type of research is not directly applicable to household pests, it is possible that future developments may lead to indoor applications.

II. Neem: a new frontier

Margosan-O™ is the first neem oil extract registered as an insecticide for non-food crops in the United States. It is a product of the neem tree Azadirachta indica which has a number of properties that act synergistically to control pests. The tree exhibits a low mammalian toxicity, can grow in arid "waste" sites, can be used as a windbreak and shade tree, and can also be used as fodder for domestic animals. In India, neem products have been used in toothpaste, in pharmaceuticals, and as grain protectants. Unfortunately, its versatility is slowing down registration procedures and its potential is not well known amongst pest control operators. Studies are being pursued in India, Israel, West Germany, the Phillipines, Togo, East Africa, and the United States. Six avenues are being followed: Preparation of extracts, chemistry of extracts, modes of action, formulation of products, laboratory and field studies of effects against certain pests, and development schemes.

Neem tree products can act as broad spectrum repellents, anti-feedants, growth regulators, and toxicants. So far, at least

123 insect, 3 mite, and 5 nematode species are affected by varios neem extracts. (The German cockroach is included in this group.) Powdered seeds suspended in water are effective against a number of pests, as is neem oil which is extracted from the seed kernel through the use of solvents. Oil extraction residues and pulp can be made into "neem cake" which has insecticidal and fertilizer properties when added to rice paddies. Leaves are used as repellents to protect woolens and grains, and leaf mulch can be used as a protectant or fertilizer (although its high protein content makes it better for animal food). Timber from the neem tree has been found to be resistant to termites and wood-boring beetles, and is useful as fenceposts, in buildings, and in furniture. The neem tree bears fruit in five years, is fully productive in ten, and lives for over two hundred. Thirty to fifty kilograms of fruit could be produced annually per tree. That coverts to 6 kg neem oil at a projected dollar per kilogram. The rest would be used in cakes valued at a little over twelve dollars.

Ethanol extracts from the seeds are safe to use on non-food crops and the following figures tell why its registration should extend to other uses. The acute oral toxicity of the extracts in mouse tests was very low (13,000 mg/kg) and no skin sensitivity was noted in guinea pigs injected with neem extracts. Neemrich 100, a formula with 30 percent neem oil, applied dermally to albino rats at daily doses of 600 mg/kg for three weeks, resulted in no overt toxicity or behavioral abnormality. A Neemrich I formulation gave an LD_{50} of 11,220 mg/kg (oral in rats) and other studies have shown that concentrations as high as 8,500 mg/kg (oral) were still not toxic to rats.

The most important ingredient in neem extracts is azadirachtin, a feeding deterrent found in the seed kernel. Ethanol extractions of this chemical from one hundred grams of neem seeds varies, but the greatest yield (4-5 percent) has been obtained using an azeotrophic mix of methyl tertiary-butyl and methanol. Precise description of the modes of action of various neem tree products is difficult due to the complex and synergistic action of the biologically active ingredients. Many active ingredients aside from the one mentioned exist and modalities have been shown to depend on the type of extract, the test insects, geographical origin of the extract, dosages, and formulations. Margosan-O™'s manufacturer estimates that it would cost up to 1.2 million dollars to complete the tests required for registration of the material for use on food crops. Small, innovative companies would find this a great impediment to marketing. It has been suggested that a less stringent registration procedure be applied, one that could be used for other low-toxicity products.

The "Neemrich" concept, proposed by researchers at the National Chemical Laboratory of India, refers to standardized extracts capable of being made through small-scale extraction processes at the village level. The recommended process has five steps and requires inexpensive solvents. Neemrich I will be the first agent of this sort to be registered, but Neemrich II and Neemrich III are being developed. Neemrich advocates believe the active ingredient should not be described chemically, and should instead be defined biologically or according to its activity.

Neem-based insecticides are well-suited for IPM programs both for food crops and within structures since the oil is not toxic to humans or the natural enemies of pests. Development of neem proucts challenges not only regulatory agencies but also the petrochemical industry. Further, the neem tree is not the only botanical pesticide that could be grown and processed locally (a reported 2121 plant species have pest control properties). Neem products may represent a new generation of pesticides, with their level of effectiveness dependent on their formulations (e.g. as spot treatments rather than for blanket coverage). Indiscriminant use could destroy the potential of neem products, resulting in their classification with synthetic pyrethroids and other petroleum-based products which have lost their effectiveness due to target-pest resistance.

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SUMMARY

A variety of control methods for termites, ants, fleas, ticks, and beetles have been reviewed in this discussion. However, when "across the board" effectiveness and minimal hazard levels in and around buildings are considered, three basic types of control stand out: desiccating dusts, temperature extremes, and insect growth regulators. The first two target moisture requirements and the need for a tolerable temperature range. The last one focuses in the molting process. It appears that when direct control tactics need to be employed, those that alter the most basic physiological processes are often the least-toxic and most effective.

Desiccating dusts include diatomaceous earth, silica dust (amorphous precipitated silica or silica aerogel), and boric acid dust. Each is long-lasting, exhibits low mammalian toxicity, and can be used in confined areas at various times during construction. Boric acid has a distinct set of advantages. For example, it can be formulated to be non-volatile, electrically charged, and anti-caking. Its coloring and bitter taste also act to discourage ingestion by children or pets. Moreover, boric acid is non-repellent (when properly applied), cost-effective, and has not caused the development of resistance in target pests. Marketing advances include more effective application equipment and water-resistant formulations.

The use of liquid nitrogen and extreme heat have been found to be effective against a number of wood-infesting insects as well as other pests that can be confined to treatment sites. Both techniques are relatively inexpensive and environmentally benign. Unfortunately, a good deal of overkill is sometimes required to ensure treatment success and a detailed description of effects on household items is unavailable.

Insect growth regulators (e.g. methoprene, hydroprene, and fenoxycarb) act against termites, ants, and cockroaches. They are biologically specific, exhibit low mammalian toxicity, and cause a number of effects in insects, including the assumption of soldier and soldier-like characteristics, loss of symbionts, failure of colony establishment, egg mortality, and sterility. Insect growth regulators can be combined with other less-toxic controls such as boric acid or with conventional insecticides to either hasten pest population reduction or to increase the effectiveness of an instituted control program. Properly clothed technician experience little risk during application, at least when exposed to fenoxycarb.

All three of these methods aim at eliminating existing pest populations from a given area, not at excluding or repelling them. Desiccating dusts and insect growth regulators can remain effective for extended periods although neither presents the hazards associated with the residues of conventional insecticides. It should be emphasized however that least-toxic control programs are founded on the presence of preventative measures, mainly habitat modification and elimination of attracting resources. Use of the dip-diffusion process for wood for example is a very appealing option in the prevention process since it is long-lasting,

relatively easy to perform, and cost-effective. Research supports the use of many of the direct and indirect control measures outlined in this review. But, it seems that pest control operators. industry, and the general public will need to be willing to make certain compromises before alternative techniques are more broadly integrated into least-toxic control programs.

50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO. EPA/101/F-90/003	2.	3. PB 90-256447

4. Title and Subtitle
Least Toxic Pest Control: How Infestations of Termites, Ants, Fleas, Ticks and Beetles can be Controlled Without Causing Short-or Long-Term Air Quality Changes and Health Risks

5. Report Date
Completed Fall 1989

6.

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8. Performing Organization Rept. No.

9. Performing Organization Name and Address
Rutger University
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10. Project/Task/Work Unit No.

11. Contract(C) or Grant(G) No.
(C)
(G)

12. Sponsoring Organization Name and Address
U.S. Environmental Protection Agency
Office of Cooperative Environmental Management
499 South Capital Street, SW A-101-F6

13. Type of Report & Period Covered
Technical Report

14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)
1405 - Least Toxic pest control: How Infestations of Termites, Ants, Fleas, Ticks, and Beetles can be Controlled Without Causing Short- and Long- Term Indoor Air Quality Changes and Health Risks

The report is part of the National Network for Environmental Management Studies under the auspices of the Office of Cooperative Environmental Management of the U.S. Environmental Protection Agency.

A number of least-toxic measures are discussed within the framework of integrated pest management systems for termites, ants, fleas, ticks, and beetles. It is presumed that adherence to such programs minimizes changes in indoor air quality and also reduces health risks by eliminating use of traditional, often hazardous pesticides. Emphasis is placed on preventative measures such as habitat modification and resource removal to eliminate conditions that encourage the establishment of and foster the growth of pest populations within the home. Control tactics are broadly categorized as chemical, biological, and physical, and are detailed in light of pertinent advances in research. Techniques relate directly to the biology of the organisms and target periods of vulnerability, symbiotic relationships between the pest and other organisms, and basic physiological processes. Boron formulations, insect growth regulators, and the use of extreme temperature seem to have the most widespread applications, although "neem" products may soon surpass even these advances

17. Docuement Analysis a. Docuement Discriptors

b. Identifier's/Open-Ended Terms

c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
	20. Security Class (This Page)	22. Price

(See ANSI-Z39.18)