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His development and use of web-based technology for reaching public groups have been considerable and include Citybugs (http://www.cnr.berkeley.edu/explore), CAL termite webpage (http://www.cnr.berkeley.edu/lewis), and website on termites for the United Nations (http://www.chem.unep.ch/pops/termitess/termite_toc.htm). Dr. Lewis' outreach and research have attracted wide media and Internet attention and have reached millions of people, nationally and internationally.

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Advances in Drywood Termite Detection and Control

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BACKGROUND

There are eight species of drywood termites found in California, among those *Incisitermes minor* (Hagen) has the greatest economic importance (Ebeling 1978, Su and Scheffrahn 1990). Each year, more than 1.5 million wood-destroying pest inspection reports are conducted in California (Brier et al. 1988). Visual evidence of drywood termites contained in industry reports suggests drywood termite infestation rates vary from 0 to 46.8% depending on county and location within structure (Ebeling and Wagner 1964, Brier et al. 1988). Costs for control and damage from drywood termites represent 5 to 20% of the > $300 million annually spent in California (Brier et al. 1988, Lewis et al. 2004). As home value escalates in California, associated costs for inspection, control, and damage repairs for drywood termites are also projected to increase. Not included in these costs are fears and perceived risk the public has toward some treatments including fumigation and heat resulting in damage to some homes in California during the last several years (Annon. 2002a, b).

INSPECTIONS

Visual searching and probing of wood including the use of flashlight and metal probe for evidence of alate wings, fecal pellets, and damage is the dominant means of inspecting for drywood termites (Scheffrahn et al. 1993). The effectiveness of visual searches for drywood termites for California conditions is unknown. Fecal pellets that are hexagonally shaped in cross-section also are considered diagnostic for the presence of drywood termites and frequently looked for during inspections (Smith 1995). Although pellet counts have been used in the laboratory to demonstrate efficacy for some chemical treatments (Scheffrahn et al. 1997), there are no published reports on the presence of chemicals in pellets that relate to whether a drywood termite infestation is active or not.

The greatest challenged faced by pest management professionals (PMPs) during their inspections is identifying the existence and limits of inaccessible drywood termite infestations. The minimum requirement for structural pest inspections is that they are visual and accessible (Structural Pest Control Board 2000). For most filed reports, areas not inspected, the most frequent language used being inaccessible to visual search. Without removing wall coverings, it is impossible to reliably determine infestations are behind walls. There have been no published reports on the frequency of drywood termite infestations, either behind walls or in inaccessible areas.

ALTERNATIVES TO VISUAL SEARCHES

There are at least seven detection devices and methods proposed as alternatives to visual searches. They include optical bore scopes, dogs, electronic odor detectors, microwaves, acoustic emission devices, infrared, and X-ray. They all claim high levels of successful detection of termites; however, few have been scientifically tested (Lewis 2003, Lewis et al. 2004, 2005).

Optical bore scopes use visible light passing through a hollow tube as a means to view termites and damage hidden away behind walls. A small hole must be drilled into walls to allow viewing. Fire blocking, insulation, and viewing through a fish-eye lens may impede the inspector's view. Optical bore scopes are currently marketed; however, their efficiency in the detection of drywood termites has yet to be scientifically tested.

Canines. Dogs have also been used to assist with drywood termite inspections, although scientific studies verifying the effectiveness are few. Several breeds of dogs have been trained, beagles being the mostly frequently used breed (Lewis et al. 1997). The mode-of-action used by dogs in finding termites, audition, olfaction, or both still needs further research (Lewis et al. 1997). For California, the effectiveness of beagles was mixed but only included subterranean termites. Drywood termites were not included in the laboratory investigations (Lewis et al. 1997). However, drywood termites were included in laboratory trials conducted in Florida, and the success rate for dogs (beagle and German shepherd) in identifying plastic containers containing drywood termites (*Cryptotermes cavifrons* Banks and *Incisitermes snyderi* (Light)) was 88.8% (Brooks 2001). False positives, canine's response to containers without drywood termites was < 1% (Brooks 2001). Currently, there are few commercial firms that train and provide dogs to assist with termite inspections.

Odor detection. Electronic odor detectors are another method of detection of termites. Their mode-of-action includes detecting methane gas, commonly produced by termites (Lewis et al. 1997). Interestingly, *Incisitermes minor*, the most important drywood termite pest in the State also has the highest methane gas production rate among termite species found in North America (Wheeler et al. 1996). One device (Termitect II) was tested on subterranean termites and produce highly variable detection rates, 20 to 100% (Lewis et al. 1997). There have been no reports on the use of electronic odor detectors in successfully identifying drywood termites.

Acoustic emissions. Termites produce vibrations in wood while feeding and by alarm calls from the head banging of soldiers. Some of these vibrations can be heard by human ear or when sounds were amplified by microphone (Emerson and Simpson 1929, Pence et al. 1954, Wilson 1971, Stuart 1988, Kirchner et al. 1994). Several genera in the Kalotermitidae also produce audible sounds (Emerson and Simpson 1929). These sounds are produced during feeding (Matsuoka et al. 1996) and by vibratory movements of workers (Leis et al. 1992, Maistrello and Sbrenna

1996). The earliest commercial audible listening device for termite feeding was an INSECTA-SCOPE. However, no data are available on its performance. Newer technology that amplifies and records termite-feeding vibrations is acoustic emission (AE). Surface and subsurface probes are available and successfully detection of drywood termites in laboratory settings is at least 80% (Lewis and Lemaster 1991, Lewis et al. 1991, Scheffrahn et al. 1993, 1997, Lewis and Haverty 1996, Lemaster et al. 1997, Lewis et al. 2004, 2005). Wall covering can impede sensor and AE performance. Distance in detection is limited to ≈80 cm along the length of a board and < 8 cm across the grain (Scheffrahn et al. 1993). Excessive background noise can also result in false positive results for active termites. AE detection equipment is commercially available, although availability is very limited.

Microwaves. These high-energy portions of the electromagnetic spectrum have been commercially available for localized control of drywood termites for at least 15 years in California (Annon. 1989). Recently, portable microwave detection devices also have been marketed in North America, including California (Anon. 2003a). Published papers using microwaves have been reported for several species of termites (Peters and Creffield 2002, Evans 2002). Success in detection of drywood termites (*Cryptotermes brevis* (Walker)) using microwaves (TERM_A_TRAC™) was 86% based on laboratory studies (Peters and Creffield 2002). Detection distance was 35 mm along the long axis of test boards and 25 mm deep below the surface. However, water in wood, wall coverings, and excessive wind and motion can lead to false positives results for live termites. The Department of Health Services regulates microwave devices in the State and has published guidelines for safe use (Title 17, California Code of Regulations, Subchapter 4, Radiation).

Infrared. This portion of the electromagnetic spectrum is nearest red in the visible range. Their existence has been known for several hundred years (Maldague and Moore 2001). Although invisible to eye, infrared energy has a penetrating heating effect and is easily felt when encountered. Most objects, living or not, give off infrared heat, whether internally generated or reflected. Initial uses of infrared were for military surveillance, as early as World War II (Maldague and Moore 2001). Today, there are many nonmilitary uses and include measurement devices, binoculars, night viewing for hunting, etc. In structures, infrared devices have been used to find faulty electrical connections and heat and water leaks in walls and roofs (Tobiasson 1994, Maldague and Moore 2001). A more recent use includes termite detection (Lewis 2003). Commercial termite detection models are available. Some testimonials and demonstrations on the termite detection ability of infrared exist (Anon. 2000); however, the effectiveness in finding termite infestations has not been scientifically tested. A possible drawback in the commercialization of this technology as a termite detection tool is that the small temperature difference between the termites and wood, at least at ambient level, may hinder this technology in locating infestations (Carroll 2002).

X-ray. These penetrating rays are part of the electromagnetic spectrum that is nearest ultraviolet rays. They are invisible, have smaller wavelength, and have a higher frequency (Hz) compared to the visible part of the spectrum (Ness et al. 1996, Maldague and Moore 2001). There are many commercial applications for X-rays and include dental, medical, military, security, and nondestructive evaluation of materials (Martz et al. 2002). X-ray energies have the ability to penetrate all materials (Martz et al. 2002). These penetrating rays have also been used to nondestructively view insects in hidden locations (Fisher and Tasker 1939; Berryman and Stark 1962a, b; Berryman 1964; Davies et al. 1988; Kim and Schatzki 2001), and internal structures of insects (Westneat et al. 2003). For viewing insects hidden in wood, X-rays have been used for at least seven decades (Fischer and Tasker 1939, Kim and Schatzki 2001). X-rays have also been used to view several structural infesting beetle pests (Fisher and Tasker 1939, Suomi and Akre 1992). Only recently has the potential use of X-ray in detecting drywood termite infestations been explored (Lewis et al. 2005). Older X-ray technology was cumbersome to use, expensive, and safety not fully understood. Today's newer technology is lightweight and portable. Processing of images is accomplished with lasers that produce digital images that are enhanced from computer software. Newer sources of X-rays emitters and advances in safety monitoring equipment minimize radiation leakage and exposure (Annon. 2003b). The Department of Health Services regulates the save use of X-ray and other radiation generating devices in the State and has published guidelines for their save use (Title 17, California Code of Regulations, Subchapter 4, Radiation).

CONTROL/MANAGEMENT

The successful control of drywood termites is more dependent on inspection findings than for subterranean termites. For subterranean termites, since continual access to water is critical for their survival, nests are ground-based. Control attempts are directed at the soil level either as chemical soil drenches, in-ground bait stations, repairs to foundation cracks, or installation of physical barriers (Su and Scheffrahn 1990, Lewis 1997, Potter 1997, Su and Scheffrahn 2000). The one exception that can occur is arboreal nests produced by the Formosan subterranean termite, *Coptotermes formosanus* (Su and Scheffrahn 1990). However, except for Hawaii (Tamashiro et al. 1987) this nesting behavior is an unusual condition for North America.

For drywood termites, the situation is dramatically different. Since they nest and forage solely in wood (Su and Scheffrahn 2000), they can literally be in any board in the structure above soil level. Visual evidence of their presence, fecal pellets and/or newly emerged alates (primary reproductives) can be far removed from the board or boards that house the nest. Boards often can be hidden behind wall coverings, perhaps installed during the original construction. Infestations also tend to have small to moderately sized colonies that have only a few thousand individuals (Su and Scheffrahn 1990). The maturation of colonies (production of reproductives) is considered slow at least 2 years (Thorne et al. 2002), often more (Harvey 1934). Consequently, infested boards can go for years unnoticed. Even when winged alates are seen, this may be of little value in identifying the site of the nest, since newly emerged alates are attracted to lights, especially windows and light fixtures in the on position.

Traditionally, control for drywood termites is either whole-structure or localized treatments. Until recently two fumigates methyl bromide and sulfuryl fluoride were marketed for whole-structure treatment of drywood termites. However, methyl bromide has been phase out due to affects to the ozone layer and international agreement (Muller 1997). Two options for whole-structure treatments remain, sulfuryl fluoride (chemical fumigant) and heat treatment considered an alternative to whole-structure fumigation (Lewis and Haverty 1996). Elimination of drywood termite infestations have been reported for sulfuryl fluoride (Stewart 1957, Su and Scheffrahn 1986, Osbrink et al. 1987, Thoms and Scheffrahn 1994, Scheffrahn et al. 1995, Lewis and Haverty 1996, Scheffrahn et al. 1997) and heat treatments (Lewis and Haverty 1996, Rust and Reierson 1997, Woodrow and Grace 1997, Scheffrahn et al. 1997, Woodrow and Grace 1998a,b,c). However, several accidents in California involving both whole-structure treatment options have caused concern over their use (Anon. 2002a,b).

Local treatments dominate treatment options used for controlling drywood termites. There are at least seven techniques/methods; marketed as more than a dozen products in North America. These methods include: electrocution, heat, microwaves, and spot applications with chemical liquids and foams. The list of chemicals is moderate and includes bifenthrin, cyfluthrin, disodium octaborate tetrahydrate, fipronil, imidacloprid, liquid nitrogen, permethrin, pyrethrum, and thiamethoxam. For California, at least 70% of treatments for drywood termites involve the local application of chemicals or nonchemical methods (Lewis 1997b, Potter 1997, Lewis et al. 2005). However, efficacy levels are highly variable depending on species of drywood termite, active ingredient, and application technique (Lewis 2003).

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