SURVEY OF THE TERMITES (ISOPTERA) OF OKLAHOMA AND INFLUENCE OF ARTIFICIAL GUIDELINES IN SOIL ON CHANNELING FORAGING SUBTERRANEAN TERMITES

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SURVEY OF THE TERMITES (ISOPTERA) OF OKLAHOMA AND INFLUENCE OF ARTIFICIAL GUIDELINES IN SOIL ON CHANNELING FORAGING SUBTERRANEAN TERMITES

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PREFACE

Chapter I of this thesis introduces research I conducted including the main objectives. Chapter II is a literature review focusing on behavior and control of subterranean termites, with special attention to the genus *Reticulitermes* (Isoptera: Rhinotermitidae). Chapters III and IV are formal manuscripts of the research I conducted during my M. S. program and are written in compliance with the publication policies and guidelines of the Entomological Society of America.

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CHAPTER I. GENERAL INTRODUCTION

Termites are the most important structural pest in the United States and are capable of causing extensive damage to houses and other wooden structures. Costs for control, prevention, and repair of termite damage can reach $2 billion annually. The distribution of termites in the state of Oklahoma is categorized as moderate to heavy, with the extreme southeastern corner of the state being very heavy (Jones 2000; Suiter et al. 2002). Despite the economic threat these structural pests pose to homeowners and business owners within the state, only limited information on the biology, behavior, and ecology of the subterranean termites of Oklahoma can be found.

Previous efforts to catalog the activity of termites in Oklahoma provide important information about seasonal flight activity (Okla. Coop. Econ. Insect Survey 1955-1992). However, in most cases this information is based on secondhand reporting, and as such, neither species identification nor specimen preservation was possible. Further, available distribution maps of the termites of the United States offer conflicting reports with respect to the species located in Oklahoma. At the time of this study, no published, concise, comprehensive survey of the termite fauna of Oklahoma could be found.

Control of subterranean termites in the U. S. has primarily relied on the use of chemical insecticides applied to the soil immediately surrounding and underneath a structure. However, in the past fifteen years baits have become a widely used alternative for achieving control. Baits take advantage of the social lifestyle and behavior of subterranean termites. Trophallaxis is the phenomenon exhibited by termites in which beneficial substances are shared among members of a colony. These substances include food, internal symbionts, and pheromones. Insect growth regulators used in baiting schemes are also readily passed between individuals during trophallaxis (Sheets et al.

2000). The theory behind baiting systems, then, is that when a bait containing such chemicals is located and fed upon by foraging termites, all individuals in the colony can potentially be eliminated.

One difficulty associated with the use of baiting systems is the placing of baits in areas where they will most likely be found by foraging termites. It may take termites several weeks or months to locate and begin feeding on installed baits. Further, placement of baits in areas arbitrarily deemed conducive to termites may not shorten this "lag time" or increase the rates of attack (Potter et al. 2001). Studies directed at enhancing baiting systems to ensure that they are readily located by termites have focused on modifying the bait itself (Reinhard et al. 2002). A study by Pitts-Singer and Forschler (2000) demonstrated that foraging termites will follow artificial guidelines placed in the soil. The possibility of using such guides to enhance the effectiveness of baits used in controlling subterranean termites has not been evaluated.

The overall objectives of this research were to gather specific biological information on the termites of Oklahoma, and to evaluate whether or not artificial guides placed in the soil can effectively direct termites to below-ground bait stations. In the first study species distribution and seasonal activity of termites occurring in Oklahoma were investigated. Further, important morphological features for species within the genus *Reticulitermes* were measured and evaluated. Species determination and morphometric measurements were made on termites from five monitoring sites across the state as well as specimens donated by various collaborators. For the second study, Plexiglas® guides were affixed to below-ground monitoring stations in order to evaluate their effectiveness at channeling foraging termites to the stations. The number and size of the guides varied between treatments. Monitoring stations without guides were used as controls. The time between installation of stations and the initial discovery of stations by foraging termites ("lag time") was recorded. Statistical analyses comparing stations with and without artificial guides were conducted on the "lag time" data as well as on the total number of control and treatment stations that became active during the study period.

Objectives

I. Examine the biology and behavior of the termites (Isoptera) of Oklahoma.

II. Determine whether artificial guidelines placed in the soil can effectively direct termites to below-ground monitoring stations.

Explanation of Thesis Format

This general introduction is followed by a literature review (Chapter II). Chapters III and IV are devoted to individual papers to be published. Chapter V is a general summary, followed by appendices. References are provided for citations in the literature review and papers to be published. The first paper (Chapter III) is a survey of the termites of Oklahoma including species determination, seasonal activity, distribution and taxonomic characteristics. In the second paper (Chapter IV) the possibility of using artificial guides to enhance below-ground bait stations is evaluated. These papers follow the general guidelines of the Entomological Society of America for submission to scientific journals.

CHAPTER II. REVIEW OF PUBLISHED LITERATURE

Background

Termites are social insects that function as primary decomposers of wood and cellulose material in many of the areas in which they exist. Despite their essential role in the detritus cycle, termites are most often recognized for the damage they cause to wooden structures. Estimates of annual costs for prevention, control, and repair of termite damage in the United States range from one-to-eleven billion dollars (Potter 1997; Jones 2000; Su 2002).

It is generally accepted that there are seven families within the order Isoptera: Mastotermitidae (primitive), Serritermitidae, Kalotermitidae, Hodotermitidae, Termopsidae, Rhinotermitidae, and Termitidae (higher termites) (Kambhampati and Eggleton 2000). Termites are also commonly classified as subterranean, drywood, or dampwood based on their ecology and preferred habitats. However, such terms do not always correspond to scientific classification as termites within the same family may have different preferred habitats. For example, most species in the family Rhinotermitidae are considered subterranean, however, one species in this family, *Prorhinotermes simplex* (Hagen), is considered a dampwood termite.

Five termite families (Kalotermitidae, Hodotermitidae, Termopsidae, Rhinotermitidae, and Termitidae) are found in the United States (Gleason and Koehler 1980). Over a third of the fifty species of termites found in the U.S. are structural pests (Thorne 1998). However, nearly ninety percent of damage and control costs can be attributed to a few species of subterranean termites within the genus *Reticulitermes* and the species *Coptotermes formosanus* Shiraki (Haverty et al. 1999b).

Control - Chemical

For the last fifty years termite control has relied primarily on the use of broad-spectrum chemical insecticides. Chlorinated hydrocarbons, which had long lasting residual effects, were used until the late 1980's when they were replaced by organophosphates and pyrethroids. Recently, boric acid has been evaluated as a soil termiticide for control of subterranean termites with limited results (Kard 2001). These insecticides are often applied to foundation soil as a pre-treatment (prior to the pouring of the concrete slab) on new construction projects. On existing structures, insecticides are applied around the inside and outside perimeter of foundations as well as under the slabs along expansion joints, settlement cracks, around utility penetrations, and behind veneers via drilling.

The goal of this type of termite control is to create a continuous chemical barrier between the termite colonies and the wooden components of the structure. Techniques for inspecting and treating many types of construction, including difficult control situations, are described by Bennett et al. (1988). These techniques include the mechanical alteration of structures to eliminate conditions which are conducive to termite invasion (e.g. reduction of moisture near or in the structure, eliminating wood to soil contact), proper termiticide treatments to soil and foundations (including concrete slab, basement, and crawl space foundations), and preservative treatment of wood used in construction.

Recently, many factors have been identified that influence the effectiveness of chemical treatments to soil. For example, termites can exploit gaps in chemical barriers as small as 3-4 cm (Kuriachan and Gold 1998). Osbrink et al. (2001) showed that economically important termites such as *C. formosanus* and *Reticulitermes virginicus*

(Banks) exhibit inter-colony and intra-colony variation in susceptibility to a range of commonly used termiticides. Their study suggests that the development of somewhat resistant surviving workers into supplementary reproductives in colonies exposed to termiticides could result in the rapid development of insecticide resistant colonies.

The effectiveness of a termiticide treatment can also be influenced by the soil composition in the area being treated. A study by Ramakrishnan et al. (2000) showed that imidacloprid, a commonly used soil termiticide, was most effective at reducing the feeding of *Reticulitermes flavipes* (Kollar) in treated sand and least effective in treated silty clay-loam soils (a soil type commonly found in Oklahoma). Finally, the number of termites being treated has been shown to affect tolerances to chemical insecticides. DeSouza et al. (2001) attributed the increased survivorship among larger groups of termites exposed to chlorpyrifos to the phenomenon of "social facilitation". Factors such as these, coupled with growing concerns from homeowners about the use of chemical insecticides in the last decade, have renewed interest in alternative methods of termite control.

Control – Alternatives

Numerous termite control alternatives have been suggested, ranging from changes in the application techniques of liquid termiticides to the use of biological control agents. Potter and Hillery (2002) showed that an exterior perimeter-only treatment of soil termiticides provided control without the need for invasive drilling through veneers or into foundations. Physical barriers using materials such as steel mesh, crushed basalt, and sand have been used to exclude termites from structures. However, the effectiveness and subsequent use of such materials is limited by the requirement for species specific effective particle size ranges and rigid quality control needed during installations (Su and Scheffrahn 1992; Yates et al. 2000). Another alternative to chemical insecticides that showed promising results in laboratory experiments is the use of natural plant extracts (Blaske and Hertel 2001). This study showed that formulated isoborneol, cedarwood oil, and two constituents of coconut oil significantly repelled termites and could possibly be effective as a treatment to soil due to their highly toxic effects, although further field studies are needed.

Although the biological control of termites has been a goal of termite researchers for nearly seventy years (Snyder 1935; Lee and Wood 1971), this area of termite control has had only limited success. Reviews by Logan et al. (1990), Grace (1997), Culliney and Grace (2000), and Rath (2000) on the biological control of termites indicate that the most promising control agents that have emerged are the two endoparasitic fungi in the class Deuteromycetes, *Beauveria bassiana* (Balsamo) and *Metarrhizium anisopliae* (Metschnikoff) Sorokin. Laboratory experiments have shown that termite species are highly susceptible to these fungi. However, little commercial use and lack of successful field trials have been attributed to a number of limiting factors, including avoidance of fungal conidia by termites, behavioral mechanisms such as the removal and isolation of infected nestmates, and defensive fungistatic secretions. Difficulty in directly introducing large quantities of conidia to foraging termites, or maintaining living fungal cultures in baits, and constraints placed on research in this area by environmental protection laws and lack of public acceptance also hinder commercial use. A study by Ramakrishnan et al. (1999) demonstrated an increased susceptibility of *R. flavipes* to *M. anisopliae* when the termites have also been exposed to imidacloprid. It is likely that the future of biological control of termites rests in integrated pest management strategies such as this.

Baits and Baiting Systems

One termite control alternative that has enjoyed considerable success and attention is the use of baits. Baiting involves the placement of below or above-ground stations containing cellulose material (i.e. wooden stakes, paper products) around the perimeter of a structure. In one baiting system, these stations are initially used to monitor for termite activity. Once activity is detected, a chemical bait is placed in the station. The bait is then consumed and passed to other members of the colony via trophallaxis. In other systems, the chemical bait is placed in the station when it is first installed, eliminating the monitoring period. Many chemicals have been evaluated for use in such baiting schemes. Bait chemicals fall into three general categories; slow-acting toxicants, juvenile hormone analogs, and chitin synthesis inhibitors (Su 1994).

In the field of slow-acting toxicants Esenther and Beal (1974, 1978) showed that mirex (dechlorane) could be used to suppress activity of *Reticulitermes* spp. Su et al. (1991) demonstrated that suppression of foraging populations of *C. formosanus* could be achieved using A-9248 (diiodomethyl para-tolyl sulfone). A study by Kard (2001) showed that boric acid (BA) is a non-repellent toxicant, and suggests that future evaluations of borates of lower water solubility than BA may identify boron compounds that can be effectively used in baiting systems. Other chemicals with similar modes of action proposed for use in baiting systems include hydramethylnon, avermectin B_1, and sulfluramid (Su et al. 1982; Su et al. 1987; Su and Scheffrahn 1991).

According to different authors, as summarized by Hrdy et al. (2001), juvenile hormone analogs (JHAs) induce many effects that lead to termite mortality including difficulties during ecdysis, loss of intestinal symbionts, and, most commonly, excessive soldier formation. Fenoxycarb, a JHA used in early bait tests, has effectively suppressed foraging activity in field colonies of *Reticulitermes* sp. (Jones 1989). Further, a carbamate derivative of 2-(4-hydroxybenzyl)-1-cyclohexanone, commonly referred to as W-328, demonstrated detrimental affects against *Reticulitermes* sp. and *C. formosanus* (Hrdy et al. 2001).

Chitin synthesis inhibitors (CHIs) interfere with the molting processes of many insects, including termites. Chemicals such as diflubenzeron, hexaflumuron, and chlorfluazuron have been evaluated for use as baits against termites (Rojas and Morales-Ramos 2001). Commercially, hexaflumuron has achieved success as the active ingredient in DowElanco's Sentricon^{TM} Termite Colony Elimination System. Laboratory studies have shown that hexaflumuron is readily distributed, slowly metabolized, and slowly cleared from termite populations (Sheets et al. 2000). The Sentricon system has been successfully used in many areas of the United States and other countries against a number of termite species including *R. flavipes* and *Coptotermes sp.* (Forschler and Ryder 1996a; Haagsma and Bean 1998; Getty et al. 2000; Prabakaran 2001; Lee 2002). This system has also been shown to be effective in difficult control sites where previous chemical control methods have failed (Kistner and Sbragia 2001) and has been shown by Grace and Su (2001) to be an effective long-term termite control option. This product is also being evaluated for use as an agricultural termite control method for citrus crops in Florida (Stansly et al. 2001).

The use of baits and baiting systems, despite their apparent success, is not devoid of enigmas. The specific methodology used to evaluate the efficacy of baiting is controversial, largely due to the difficulty associated with assessing just what effects and level of control these baits exhibit on the hidden nests of subterranean termites (Su 1994; Forschler and Ryder 1996b; Thorne and Forschler 2000; Evans 2001; Rojas and Morales-Ramos 2001). Non-target species, especially some ant species, which may exclude termites from a station, are commonly found within in-ground monitoring and bait stations (Gulmahamad 1998; Scharf et al. 2002). Because molting normally is inhibited as temperatures decrease, the effects of insect growth regulators like JHAs and CHIs are also significantly influenced by temperature (van den Meiracker et al. 2001). Further, consistent monitoring of baits is necessary and time consuming for pest control operators. To reduce time on site, Su (2001b) demonstrated that a computerized remote monitoring system that detects breakage of a circuit within the bait station can be used to relieve the time required to conduct labor-intensive visits and to increase the frequency of termite detection.

Another problem associated with baiting systems is that foraging termites find a very low percentage of installed bait stations. Henderson et al. (1998) showed that directed placement of baits in areas conducive to termites around structures increased the chance that the baits became active. This study is contrasted by the findings of Potter et al. (2001) who found no significant difference in rates of attack on monitors placed in areas thought to be conducive to termite foraging. They suggest that pest control operators would most likely not be able to predict "with any degree of reliability" the likely locations of termite foraging and subsequent preferential bait placements. A recent study by Reinhard et al. (2002) identified the potential for using the natural phagostimulant hydroquinone to attract termites to in-ground stations.

As the use of new, directed termite control methods increase so too does the need for a better understanding of basic termite biology. Species identification and distribution, colony structure and flight times, varying wood preferences and consumption rates, and foraging behavior are all important features to understand.

Species Identification

The literature contains many keys to United States termites by several authors (Banks and Snyder 1920; Banks 1946; Snyder 1954; Gleason and Koehler 1980; Nutting 1990; Scheffrahn and Su 1994). However, the reliability of species identification within the genus *Reticulitermes* using any of these published keys has been called into question (Thorne 1998; Jones 2000). Weesner's call for revision of this genus, "certainly this genus is woefully in need of a critical taxonomic study", has recently been echoed by various authors (Weesner 1970; Haverty and Nelson 1997; Thorne 1998; Haverty et al. 1999a; Jones 2000).

Identifications are made based on the soldier and alate castes. The most reliable way to identify species is to collect both castes from the same colony. This is difficult because soldiers make up a low percentage of the caste ratio and alates are not always present in the termite populations of a given colony. Identification is further complicated by the possibility of hybridization between species within this genus, specifically between *Reticulitermes tibialis* Banks and *Reticulitermes heperus* Banks (Pickens 1934), and between *R. flavipes* and *R. virginicus* (Banks 1946; Howard et al. 1981). Finally, many recent taxonomic studies have revealed that specimens from different colonies of

Reticulitermes currently identified as the same species may have multiple cuticular hydrocarbon phenotypes. Because cuticular hydrocarbon phenotypes are thought to be species specific among termites, the authors of these studies suggest that a number of undescribed taxa within the genus exist in various locations throughout the United States (Haverty et al. 1991; Haverty et al. 1996; Haverty and Nelson 1997; Haverty et al. 1999a; Jenkins et al. 2000; Nelson et al. 2001).

Species Distribution

Correct identification is vital to understanding distributions of termite species. The exact distributions of *Reticulitermes* sp. are not well known. A majority of the state of Oklahoma has a "moderate-to-heavy" termite distribution, with the extreme southeastern corner of the state being "very heavy" (Jones 2000; Suiter et al. 2002). Snyder (1954) reported that three species of *Reticulitermes* occurred in Oklahoma, *R. flavipes* (the eastern subterranean termite), *R. tibialis* (the arid-land subterranean termite), and *R. virginicus* (the dark southern subterranean termite). Weesner (1970) reported that *Reticulitermes hageni* Banks (the light southern subterranean termite) had been collected from Tulsa, Oklahoma. Nutting's (1990) distribution maps show *R. hageni*'s range to include Oklahoma but that of *R. virginicus* to extend westward only as far as western Arkansas and Missouri. Weekly reports of pestiferous insects in the state of Oklahoma published from 1955 through 1993 indicate that all four species of *Reticulitermes* occur in the state and that occasional invaders include the dry-wood termite *Incisitermes minor* (Hagen) and damp-wood termites in the genus *Zootermopsis* (USDA 1951-1975; USDA 1976-1992; Okla. Coop. Econ. Insect Survey and Detection Report 1956-1992).

Currently, no published, concise, comprehensive survey of the termite fauna of Oklahoma could be found.

Colony Structure

Subterranean termite colonies exhibit social polymorphism with an organized caste system. These castes include immatures (larvae), nymphs (intermediate), soldiers, workers, and reproductives (primary king and queen; supplementary reproductives). It has been the general assumption that these colonies are "closed" systems in which all individuals are the progeny of a single founding king and queen, and that the primary mode of dispersal among termites is the result of seasonal flights when primary reproductives establish new colonies.

However, recent genetic and behavioral studies have shown that colonies are more dynamic than previously thought and are often established by budding, in which a number of secondary reproductives, workers, and soldiers become isolated from the main colony, producing an entirely new colony without a mating flight (Thorne et al. 1999). A recent mitochondrial DNA study by Jenkins et al. (1999) demonstrated that individuals of the same colony may have different maternal lineages, indicating the possibility of colony fusion (two separate colonies merging into one) in *Reticulitermes*. Colony fusion was also demonstrated by Matsuura and Nishida (2001) by assessing agonistic behaviors among laboratory colonies of *Reticulitermes speratus* Kolbe. Finally, a genetic study by Bulmer et al. (2001) revealed that colonies of *R. flavipes* can have a variety of modes of reproductive organization ranging from colonies headed by a single pair of primary reproductives, to colonies containing multiple secondary reproductives, to large colonies containing offspring of multiple unrelated queens. These studies demonstrate the variability of subterranean termite colony structure.

Foraging Behavior

The cryptic nature of subterranean termites makes gathering specific information on their foraging behavior difficult. Previous studies have estimated a single subterranean termite colony foraging territory to cover several hundred to a few thousand square meters (Jones 1990; Su et al. 1993; Su 2001a), and contain up to five-to-seven million foraging termites (Jones 1988; Su et al. 1993).

The foraging behavior of subterranean termites is influenced by a number of abiotic factors that include soil type and moisture content, soil temperature, and season. Foraging has been shown to be most intense during summer months with daily peaks occurring around noon in winter and in late morning and afternoon during the summer (Nutting et al. 1975; Haverty et al. 1999b; Evans and Gleeson 2001). Temperature and moisture preferences are somewhat species specific with *R. tibialis* and *R. flavipes* preferring to forage during periods of cool temperatures and high moisture. Others, such as *Heterotermes aureus* Snyder and *R. hageni*, forage during periods of extended heat and relatively low moisture (Nutting et al. 1975; Jones 1988; Haagsma and Rust 1995; Houseman et al. 2001). Foraging is also affected by soil type. Subterranean termites are more prevalent in sandy soils than in clay-loams (Jones 1988). Puche and Su (2001) demonstrated that higher termite densities result in an increase in foraging activity. Termites have been shown to follow artificial guidelines and tunnels in the soil which may help them find food sources more readily (Pitts-Singer and Forschler 2000). Furthermore, a study by Haagsma and Rust (1995) suggests that due to the presence of irrigation, temperature-controlled buildings, and increased food resources, urban settings may be more conducive to termite foraging than their native habitat.

Flight Times

Seasonal flights of winged primary reproductives result in the dispersal and foundation of new colonies. Termites are considered relatively weak fliers but reports of alate collections at altitudes of 1000 – 3000 feet demonstrate their capability of some long distance dispersal (Light 1934; Snyder 1935). It has been suggested that many factors influence the timing of these nuptial flights, including species differences, season, geographic location, temperature, soil moisture, changing light intensity or barometric pressure, and atmospheric electricity (Snyder 1935; Nutting 1969; Thorne 1998). Most flights occur on warm days during the spring and summer following rain, although smaller fall flights are common. In areas where these specific conditions are not met, such as the northern range of *R. flavipes*, flights may be rare and dispersal may depend entirely on the phenomenon of budding (Thorne 1998). Despite these many variables, predictable peak flight dates have been established for many species across their distributions. *R. flavipes* peak flights occur from February through May, flights of *R. virginicus* peak from March to June, whereas peaks of *R. hageni* occur later in the year around August (Snyder 1954; Weesner 1970; Jones 2000). Flights of *R. tibialis* are more variable and occur over a wide range depending on the geographic location (Weesner 1970). Seasonal flight data offer further clues for correct species identification, both by comparison with known peak flight times for specific species and by providing winged reproductives which are readily identified. These data can also indicate the relative age and approximate establishment time of a specific colony as nuptial flights normally do not occur from young colonies.

Wood Preferences and Consumption Rates

It is useful to determine any preferences that subterranean termites may have for specific species of wood, both for well-informed construction practices and improved control techniques. A study by Smythe and Carter (1970) demonstrated wood preferences exhibited by three species of subterranean termites, *C. formosanus*, *R. flavipes*, and *R. virginicus*. In choice tests these three species preferred sugar maple, loblolly pine, and slash pine to redwood and ponderosa pine. This and similar studies often use wood consumption rates to indicate feeding preferences (Ripa et al. 2002). Several authors, as reviewed by Thorne (1998), have identified various factors affecting wood consumption rates of termites including temperature in the laboratory or field, caste ratios of the colonies being tested, termite mortality during the study period, and size of wood resource used in the study. Getty and Haverty (1998) showed not only that termites consumed more wood with some level of fungal decay than sound wood but that the type and stage of fungal decay also is significant. Furthermore, in choice-feeding tests *C. formosanus* was shown to prefer wood with previous feeding damage to undamaged wood (Delaplane and LaFage 1989). These confounding factors make comparisons between studies and comparisons to field conditions ambiguous (Thorne 1998). Despite these inherent problems associated with the use of consumption rate data, it is likely that wood consumption rates will continue to be a valuable tool in well constructed laboratory and field studies in the future.

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CHAPTER III: SURVEY OF THE TERMITES (ISOPTERA) OF OKLAHOMA

Abstract

Four species of *Reticulitermes* (Isoptera: Rhinotermitidae), *R. flavipes*, *R. virginicus*, *R. tibialis*, and *R. hageni*, as well as *Gnathamitermes tubiformans* (Buckley) are identified as being endemic to Oklahoma. Non-subterranean termites including the dampwood termites *Zootermopsis angusticollis* (Hagen) and *Zootermopsis nevadensis* (Hagen), and the drywood termites *Cryptotermes brevis* (Walker) and *Incisitermes minor* (Hagen), are occasionally reported in lumber and furniture shipped to Oklahoma from California and Oregon, or from gulf coast states. Fourteen morphological measurements of *Reticulitermes* sp. soldiers, including pronotal width, showed considerable interspecific overlap between *R. flavipes* and *R. virginicus*. Among colonies whose species identification was confirmed with winged reproductives, the ratio of soldier head capsule length without mandibles to head capsule width, separated these two similar species. Data on species distribution, flight times, and foraging densities are also reported.

Introduction

The geographic boundaries of Oklahoma encompass a wide variety of soil and vegetation types, from arid high desert plains to temperate forested weather conditions. The state slopes from the high western panhandle with elevations over 1370m (4500ft) above sea level and an average annual rainfall of less than 38cm (15in), to the southeastern corner with elevations less than 107m (350 ft) and average annual rainfall of 114cm (45in). Soil types range from sandy loams to heavy clays to 'rocky' schists. There are representative vegetation types of the Rocky Mountains, high-plains prairies, tall-grass prairies, Ozark hardwoods, and coastal plain forests. Moisture, temperature, soil type, and dominant vegetation are known to influence termite foraging and abundance (O. L. Williams 1934; Whitford 1999; Evans and Gleeson 2001).

The location and climate of the state also serves as a transition overlap between eastern and western termite fauna. However, there are conflicting reports as to which species occur in the state. Snyder (1954) recognized three termite species in Oklahoma: *Reticulitermes flavipes* (Kollar), *Reticulitermes tibialis* Banks, and *Reticulitermes virginicus* (Banks). More recently, Weesner (1970) and Nutting (1990) include the light southern subterranean termite *Reticulitermes hageni* Banks but exclude *R. virginicus*. Oklahoma lies at the extreme western edge of the distribution for these two eastern species.

The differences in reported ranges are probably due to the lack of a comprehensive survey of the termites of the state. Differences may also be due to the difficulty of identification of species within the genus *Reticulitermes*. Banks' (1946) morphometric study of this genus revealed interspecific overlap in all thirteen characteristics measured between soldiers of *R. virginicus* and *R. flavipes*. In situations where correct species identification is tentative based on the soldier caste, alates from the same colony are the most reliable source of confirmation. Weesner (1970) in her discussion of the termites of the Nearctic Region stated that in the Midwest (including Oklahoma) considerable variation exists among alates of *Reticulitermes* sp. However, specific information on just how they vary was not given.

This survey reports on current collections that represent most of Oklahoma as well as morphological characteristics of individual termites from several colonies. The objectives of this study are to: establish the termite species of the state, determine species range within the state, and gather morphological and seasonal data of *R. flavipes* and *R. virginicus* that may aide in correct species identification.

Materials and Methods

Monitoring Locations. Soil and vegetation maps of Oklahoma provided by the Department of Plant and Soil Sciences Oklahoma State University (OSU) were evaluated with the aid of Dr. James H. Stiegler (soil management specialist and department head). Oklahoma is divided into five major regions based on predominant soil and vegetation types (Fig. 3.1). These regions are herein categorized (from west to east) as the short-grass high plains, mixed-grass plains, tall-grass prairies, Cherokee prairies, and Oak-Hickory/Pine forests. Monitoring locations were established in each of the regions, at Goodwell in the panhandle, Mangum in the southwest, Stillwater in the central region, Haskell in the northeast, and Idabel in the extreme southeast (Fig. 3.1). These locations were checked monthly for termite activity from March through October 2001.

Monitoring Devices. Ten below-ground monitoring stations (Fig. 3.2a,b) and thirty soil-surface ground-boards (Fig. 3.2c,d) were installed at each monitoring location. Surface ground-boards consisted of 30.5 X 15.2 X 2.5-cm (12.0 X 6.0 X 1.0-in) sections of pine/spruce/fir. Surface vegetation was removed immediately under each board to allow direct wood-soil contact. A brick was used to secure each board in place. Monitoring stations consisted of 20.3-cm (8.0-in) sections of 10.2-cm (4.0-in) inside diameter polyvinyl chloride (PVC) pipe. Four parallel, equidistant, vertical rows of twelve 3.2-mm (1/8-in) holes spaced 1.3-cm (1/2-in) apart were drilled in each section beginning 1.3-cm (1/2-in) from the bottom end. Each station was fitted with a standard 10.2-cm (4.0-in) PVC cap on top, and contained a bait matrix that consisted of seven 17.8 X 6.4 X 0.6-cm (7.0 X 2.5 X 0.25-in) pine sapwood slats with tongue depressor spacers. Each bait matrix was bound with galvanized steel wire and wrapped with a section of cardboard. Stations were vertically inserted 15.2-cm (6-in) into the soil so that all of the drill holes were below the soil surface, and the bottom was open.

The matrices and cardboard were dried at 36.7°C (98.0°F) for twenty-four hours and weighed using a Mettler PM 600 analytical balance prior to installation. Matrices from stations that became active during the study were removed and replaced following extended periods of feeding. Termites and mud tubes were removed from extracted matrices, and remaining cellulose material was redried and weighed. Differences between initial and final weights were divided by the number of days the station had been active, providing wood consumption rates.

Collections and Identifications. Termites were collected from September 2001 to August 2002. Collections were made from active stations and ground-boards as well as nearby infested tree stumps and buildings. Soldiers and alates (if possible) were collected and preserved in 70-100% ethyl alcohol. Preserved specimens were brought back to the lab for identification. Specimens were also submitted by cooperating pest control operators and faculty/staff of the Department of Entomology and Plant Pathology, OSU.

Species identifications were made using keys published by Banks (1946), Snyder (1954), Nutting (1990), and Scheffrahn and Su (1994). Soldier morphological measurements ($n \geq 5$) were recorded for 11 colonies of *R. flavipes*, 8 colonies of *R. virginicus*, 2 colonies of *R. tibialis*, and 1 colony of *R. hageni*. In instances where both alates and soldiers from the same colony were collected, morphological measurements were recorded for both castes. Alates were used to confirm the identification of 6 colonies of *R. flavipes* and 4 colonies of *R. virginicus*. Measurements were taken using a stereomicroscope equipped with an ocular micrometer and were recorded to the nearest hundredth of a millimeter. Total lengths of alates were measured from the posterior margin of the wing to the anterior margin of the head capsule. An explanation of soldier morphological measurements taken is given in Table 3.1.

Additional information was gathered from preserved termite specimens collected in Oklahoma and housed in the K.C. Emerson Insect Museum, OSU, as well as weekly insect survey and detection reports published by the Oklahoma Cooperative Extension Service from 1955-1992 (Okla. Coop. Econ. Insect Survey and Detection Report 1955-1992).

Results

Termite Species. The current survey identified *R. flavipes*, *R. virginicus*, *R. tibialis*, and *R. hageni*. Specimens from a colony of *Gnathamitermes tubiformans* (Buckley) that were collected in Tillman Co. by Don C. Arnold are preserved in the K.C. Emerson Insect Museum, OSU. Two species of dampwood termites, *Zootermopsis angusticollis* (Hagen) and *Zootermopsis nevadensis* (Hagen) have been reported in lumber shipped from Oregon and California (Okla. Coop. Econ. Insect Survey and Detection Report 1955-1992). Two species of drywood termites, *Cryptotermes brevis* (Walker) and *Incisitermes minor* (Hagen), have been reported in cabinets, furniture, and shelving material (Okla. Coop. Econ. Insect Survey and Detection Report 1955-1992). A list of the reports of dampwood and drywood termite infestations is given in Table 3.2.

Morphological Characteristics. Mean measurements of morphological characteristics of soldiers from all colonies, and only those colonies whose identification was confirmed with alates, are given in Tables 3.3 and 3.4, respectively. No single characteristic proved to be consistent for differentiating *R. flavipes* from *R. virginicus* in every identified colony. However, among those colonies whose identification was confirmed with alates, the ratio of the head capsule length without mandibles to the head capsule width at its widest point consistently separated these two similar species (Table 3.4). Results of t-tests indicated significant differences ($P \leq 0.05$) in eight of the morphological measurements. However, interspecific overlap occurred in all but the head capsule ratio. The mean total body length of *R. flavipes* alates with wings was 9.91 ± 0.40mm (n=30) with a minimum of 9.10mm. The mean total body length of *R.*

virginicus alates with wings was 8.58 ± 0.34mm (n = 18) with a maximum of 9.03mm. This measurement was also consistent at separating *R. flavipes* from *R. virginicus*.

Species Distribution. A summary of species identified by region is given in Table 3.5. *R. flavipes* constituted over half (53%) of the colonies identified. This species was identified as far south and east as Tom, OK, as far north as Bartlesville, and as far west as Stillwater. *Reticulitermes virginicus* was identified from Idabel, OK in the southeast, Catoosa and Stillwater in the northeast, Mangum in the southwest, and Lake Optima in the panhandle. During the survey only two colonies of *R. tibialis* were identified. Both these colonies were located in the panhandle, one at Goodwell and the other at Lake Optima. However, previous reports have identified this species as far east as Tulsa. *R. hageni* has also been reported from Tulsa, and specimens of this species were collected in extreme southeast Oklahoma at Ft. Towson on 8 August 2002. Fig. 3.3 is a map showing the locations of current identifications as well as previous reports.

Termite Foraging Densities. During this survey, activity was recorded in 11 monitoring stations (22%) and 15 ground boards (10%). The greatest number of active monitoring devices was recorded at the Idabel site on the 120-day evaluation (Fig. 3.4). The least amount of activity was recorded at Goodwell with just two ground-boards becoming active during the entire study period. Only four of the eleven monitoring stations were attacked significantly enough for a wood consumption rate measurements to be calculated (Table 3.6).

Flight Data. Flights of *Reticulitermes* in Oklahoma are most prevalent from March to May with occasional fall flights (Okla. Coop. Econ. Insect Survey and Detection Report 1955-1992; Fig. 3.5). Flights of *R. flavipes* recorded in 2002 occurred about one month earlier than those of *R. virginicus*, with *R. flavipes* flights from mid-March to late April and those of *R. virginicus* from mid-April to mid-May (Table 3.7). Overlap in flight dates for these two species occurred from mid-to-late April.

Discussion

Previous lists of the termite fauna of Oklahoma included *R. flavipes* and *R. tibialis* but differed with respect to the two species *R. hageni* and *R. virginicus* (Snyder 1954, Weesner 1970, Nutting 1990). Results of the current survey confirm the presence of four endemic *Reticulitermes* species in Oklahoma including *R. flavipes*, *R. virginicus*, *R. tibialis*, and *R. hageni*. Further, the collection of specimens of a colony of *G. tubiformans* from Tillman Co. indicate that this species is also endemic to the state. However, further research is needed to establish the range of this species within Oklahoma, which probably represents the northernmost boundary of its distribution. It should be noted that the instances of non-subterranean termite infestations (Table 3.2) were reported from materials shipped to Oklahoma from western states. Currently, there are no known incidences of these species becoming established in Oklahoma.

Published maps of the distribution of *R. virginicus* show its western most boundary to extend only as far as western areas of Missouri, Arkansas, and Louisiana as well as a small section in eastern Texas (Nutting 1990). Colonies of this species were identified in the current study as far west as Texas Co. in the panhandle, as well as in all four other major soil and vegetation regions. These identifications indicate, that the distribution of *R. virginicus* is probably continuous throughout the state, and that its distribution extends much further west than previously reported.

Difficulty in using published keys to correctly identify species within the genus *Reticulitermes* has been expressed by many authors (Gleason and Koehler 1980; Haverty et al. 1996; Haverty and Nelson 1997; Thorne 1998; Jones 2000; Jenkins et al. 2000; Nelson et al. 2001). In Florida, Hostettler et al. (1995) reported that a soldier minimum pronotal width of 0.88 mm for *R. flavipes* separates it from *R. virginicus* (maximum pronotal width = 0.83mm). The report set a threshold for separating these two species at 0.85mm. However, in the current study two colonies of *R. flavipes* that were confirmed with alate identification had mean (n = 5) soldier pronotal widths below this threshold (0.80mm and 0.82mm). Additionally, one colony of *R. virginicus* that was confirmed with alate identification had a mean (n = 5) soldier pronotal width above 0.85mm (0.88mm). In all three of these cases the ratio of soldier head capsule length to head capsule width correctly identified these colonies. These results indicate that grouping soldiers of *Reticulitermes* by pronotal widths alone may lead to equivocal species determinations.

Limited information due to the low percentage of monitoring devices attacked in this study makes conclusions concerning termite densities difficult. However, the differences in wood consumption rate data coupled with the higher percentage of monitoring devices attacked at the Idabel site is most likely a reflection of elevated termite densities in the southeast which decrease moving toward the northwest. This pattern of termite densities would correspond to favorable environmental conditions such as rainfall and temperature. This conclusion is supported by published termite distribution maps (Jones 2000; Suiter et al. 2002) that indicate increased termite densities in the extreme southeast corner of Oklahoma. Also, flight data described herein corresponds to known patterns in other areas of the United States (Snyder 1954). Alates of *R. flavipes* and *R. virginicus* readily keyed to species.

As termite control strategies become more directed, the need for increased understanding of basic termite biology grows. The results of this study provide information on the species, morphological characteristics, distribution, and seasonal activity of the termites of Oklahoma. These results not only add to the base of knowledge of termite biology but also provide information that pest control operators and homeowners can utilize to make well informed control strategy decisions.

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Table 3.1. Explanations of soldier morphological measurements.

Measurement	Explanation
Pronotal Width	Width of pronotum at its widest point.
Length Thorax + Abd[1]	Length from anterior margin of pronotum to tip of abdomen along the midline.
Length of Head w/ Mds[2]	Length from posterior margin of head capsule to tip of mandibles.
Total Length of Soldier	Length from tip of mandibles to tip of abdomen along the midline.
Length of Head w/o Mds	Length from posterior margin of head capsule to clypeo-labral suture along the midline.
Head Posterior Width	Width of head capsule at its widest point posteriorly before narrowing to join the pronotum.
Labral Width	Width of intact labrum at its widest point.
Labral Length	Length of intact labrum from clypeo-labral suture to tip of labrum.
Gula Width Broad (B)	Width of gula at its widest point.
Gula Width Narrow (N)	Width of gula at its narrowest point.
Gular Ratio (B/N)	Width of gula at its widest point divided by the width of the gula at its narrowest point.
Total Length/Head	Total length of soldier with mandibles divided by the length of the head with mandibles.
Length of Left Md	Length of dissected left mandible from posterior margin of apodemes to tip of mandibles.
Head Length/Width	Length of head without mandibles divided by the width of the head.

[1] Abd = abdomen

[2] Md(s) = mandible(s)

Table 3.2. Dates and locations of reported dampwood and drywood termite infestations based on records in Oklahoma cooperative economic insect survey and detection report (1955-1992).

Species	Location	Date
Zootermopsis sp.	Noble Co.	11 Dec. 1987
	Oklahoma City	23 April 1981
	Norman	15 May 1981
	Oklahoma City	2 Oct. 1981
Zootermopsis angusticollis	Duncan	25 Feb. 1955
	Oklahoma City	1 July 1977
	Oklahoma City	19 Dec. 1988
Zootermopsis nevadensis	Comanche Co.	22 Jan. 1966
Drywood (undetermined)	Claremore	10 Dec. 1976
	Tahlequah	15 June 1990
Cryptotermes brevis	Stillwater	3 June 1988
Incisitermes sp.	Durant	1 Nov. 1982
	Duncan	6 Sept. 1984
Incisitermes minor	Guthrie	5 Aug. 1957
	Tulsa	20 Oct. 1978
	Tulsa	3 Nov. 1978
	Miami	7 Mar. 1980
	Disney	29 Sept. 1981
	Duncan	21 Oct. 1983

Table 3.3. Soldier morphological characteristics for all colonies identified (min. 5 soldiers per colony).

Characteristic	*R. flavipes* (n = 56)	*R. virginicus* (n = 45)	*R. tibialis* (n = 10)	*R. hageni* (n = 8)
Pronotal Width	0.869 ± 0.049	0.792 ± 0.061	0.752 ± 0.043	0.614 ± 0.018
Length of Thorax + Abd[1]	2.839 ± 0.170	2.624 ± 0.295	2.575 ± 0.218	2.081 ± 0.081
Length of Head w/ Mds[2]	2.739 ± 0.146	2.590 ± 0.265	2.380 ± 0.170	2.086 ± 0.053
Total Length of Soldier	5.578 ± 0.272	5.214 ± 0.520	4.955 ± 0.368	4.168 ± 0.126
Length of Head w/o Mds	1.827 ± 0.105	1.780 ± 0.208	1.630 ± 0.108	1.455 ± 0.025
Head Posterior Width	1.152 ± 0.067	1.067 ± 0.076	0.985 ± 0.047	0.834 ± 0.012
Labral Width	0.345 ± 0.027	0.310 ± 0.035	0.308 ± 0.067	0.285 ± 0.018
Labral Length	0.374 ± 0.047	0.342 ± 0.051	0.300 ± 0.074	0.286 ± 0.043
Gula Width Broad (B)	0.487 ± 0.023	0.446 ± 0.027	0.437 ± 0.016	0.364 ± 0.004
Gula Width Narrow (N)	0.232 ± 0.022	0.205 ± 0.015	0.236 ± 0.008	0.178 ± 0.006
Gular Ratio (B/N)	2.109 ± 0.171	2.181 ± 0.178	1.852 ± 0.065	2.045 ± 0.055
Total Length/Head	0.491 ± 0.014	0.497 ± 0.020	0.481 ± 0.013	0.501 ± 0.007
Length of Left Md	1.071 ± 0.057	1.003 ± 0.098	0.927 ± 0.041	0.800 ± 0.030
Head Length/Width	1.590 ± 0.118	1.665 ± 0.114	1.654 ± 0.051	1.746 ± 0.044

Mean ± SD, expressed in mm.

[1] Abd = abdomen

[2] Md(s) = mandible(s)

Table 3.4. Soldier morphological characteristics for colonies that were confirmed with alate identification.

Characteristic	***R. flavipes*** **(n = 30)**	***R. virginicus*** **(n = 16)**	**Sig.(S)/Not Sig.(NS)**[a]
Pronotal Width	0.860 ± 0.046	0.849 ± 0.035	NS
Length of Thorax + Abd[1]	2.854 ± 0.176	2.873 ± 0.267	NS
Length of Head w/ Mds[2]	2.707 ± 0.145	2.939 ± 0.076	S
Total Length of Soldier	5.561 ± 0.289	5.812 ± 0.328	S
Length of Head w/o Mds	1.800 ± 0.115	2.054 ± 0.069	S
Head Posterior Width	1.172 ± 0.048	1.151 ± 0.051	NS
Labral Width	0.341 ± 0.030	0.339 ± 0.028	NS
Labral Length	0.369 ± 0.042	0.368 ± 0.047	NS
Gula Width Broad (B)	0.488 ± 0.020	0.468 ± 0.022	S
Gula Width Narrow (N)	0.235 ± 0.024	0.201 ± 0.006	S
Gular Ratio (B/N)	2.094 ± 0.189	2.325 ± 0.119	S
Total Length/Head	0.487 ± 0.013	0.507 ± 0.018	S
Length of Left Md	1.063 ± 0.050	1.069 ± 0.052	NS
Head Length/Width	1.535 ± 0.067	1.785 ± 0.052	S

Mean ± SD, expressed in mm.

[a] Significance calculated using t-test at $P \leq 0.05$

[1] Abd = abdomen

[2] Md(s) = mandible(s)

Table 3.5. Summary of species identification and corresponding collection dates by region.

Region	Species	Caste used for I.D.	Collection Dates
Short-grass High Plains	*R. virginicus*	Soldiers	1-May-02
		Soldiers and Alates	1-May-02
	R. tibialis	Soldiers	25-Sept-01 (2)[a]
Mixed-grass Plains	*R. virginicus*	Soldiers	20-Aug-01
		Soldiers and Alates	24-Apr-02
Tall-grass Prairies	*R. flavipes*	Soldiers	17-Sept-01, 26-Mar-02
		Alates	1-Apr-02
	R. virginicus	Alates	19-Apr-02 (2)
		Soldiers and Alates	25-Apr-02, 1-May-02
Cherokee Prairies	*R. flavipes*	Soldiers	26-Feb-02, 12-Mar-02, 5-Apr-02 (2), 18-Apr-02 (2)
		Alates	18-Mar-02, 9-Apr-02, 30-Apr-02
		Soldiers and Alates	29-Mar-02
	R. virginicus	Soldiers	13-Aug-01, 12-Mar-02
		Alates	30-Apr-02, 16-May-02
Oak-Hickory/Pine Forest	*R. flavipes*	Soldiers and Alates	16-Apr-02 (4), 8-Apr-02
	R. virginicus	Soldiers	29-Aug-01
	R. hageni	Soldiers	8-Aug-02

[a] Numbers in parenthesis indicate multiple colonies of the same species collected on the same date.

Table 3.6. Comparison of wood consumption rates.

Location	Station #	Wood Consumed[a]	Activity Period[b]	Consumption Rate[c]
Idabel	7	44.47	30	1.48
Haskell	5	68.04	34	2.00
Mangum	5	40.81	61	0.67
Mangum	4	45.24	92	0.49

[a] grams

[b] days

[c] grams/day/one monitoring station

Table 3.7. Flight records of *Reticulitermes* for 2002 in Oklahoma by species.

Species	Date	City	County
R. flavipes	18 March	Tulsa	Tulsa
(median date = 9 April)	26 March	Stillwater	Payne
	29 March	Bartlesville	Washington
	1 April	Stillwater	Payne
	9 April	Tulsa	Tulsa
	16 April (III)[a]	Idabel	McCurtain
	30 April	Bixby	Tulsa
R. virginicus	19 April (II)[b]	Stillwater	Payne
(median date = 28 April)	24 April	Mangum	Greer
	25 April	Stillwater	Payne
	30 April	Jenks	Tulsa
	1 May	Stillwater	Payne
	1 May	Slapout	Beaver
	16 May	Tulsa	Tulsa

[a] Alates from three colonies of *R. flavipes* were collected from the Idabel area on 16 April 2002.

[b] Alates from two colonies of *R. virginicus* were collected from the Stillwater area on 19 April 2002.

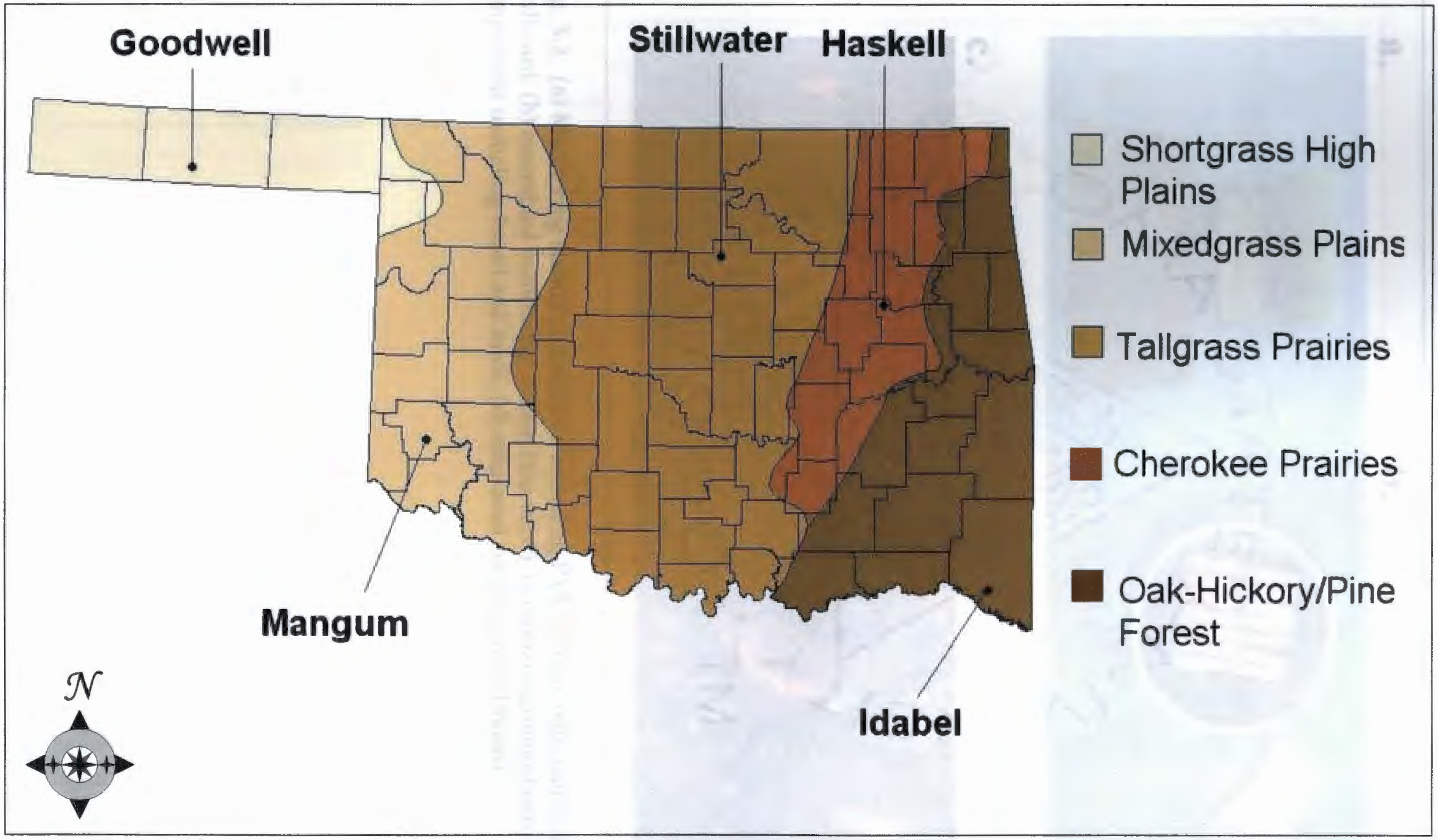

Fig. 3.1. Regional divisions of Oklahoma based on predominant soil and vegetation types.

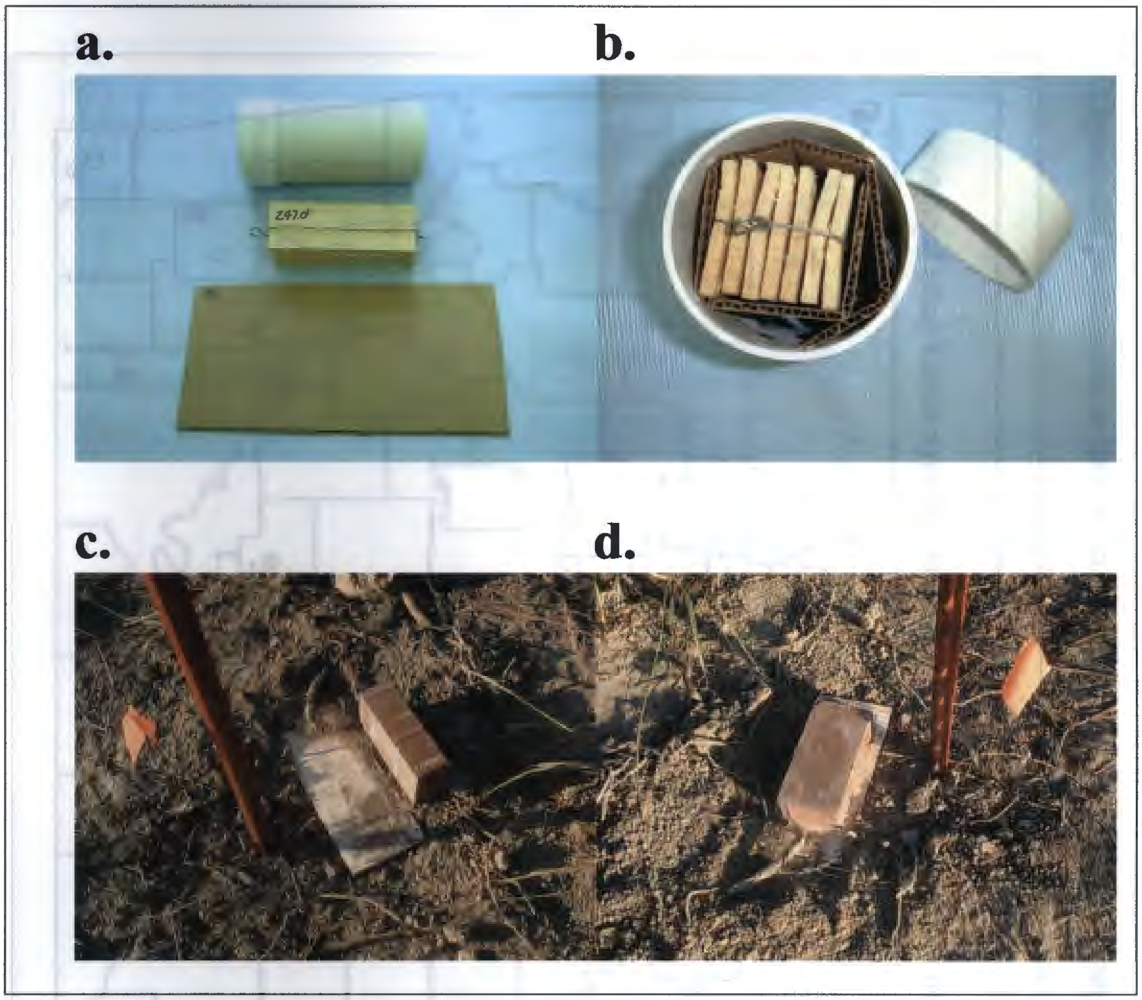

Fig. 3.2. (a) Monitoring station components including PVC station, bait matrix, and cardboard, (b) assembled monitoring station (top view), (c) surface ground-board components including board and brick, (d) emplaced surface ground-board.

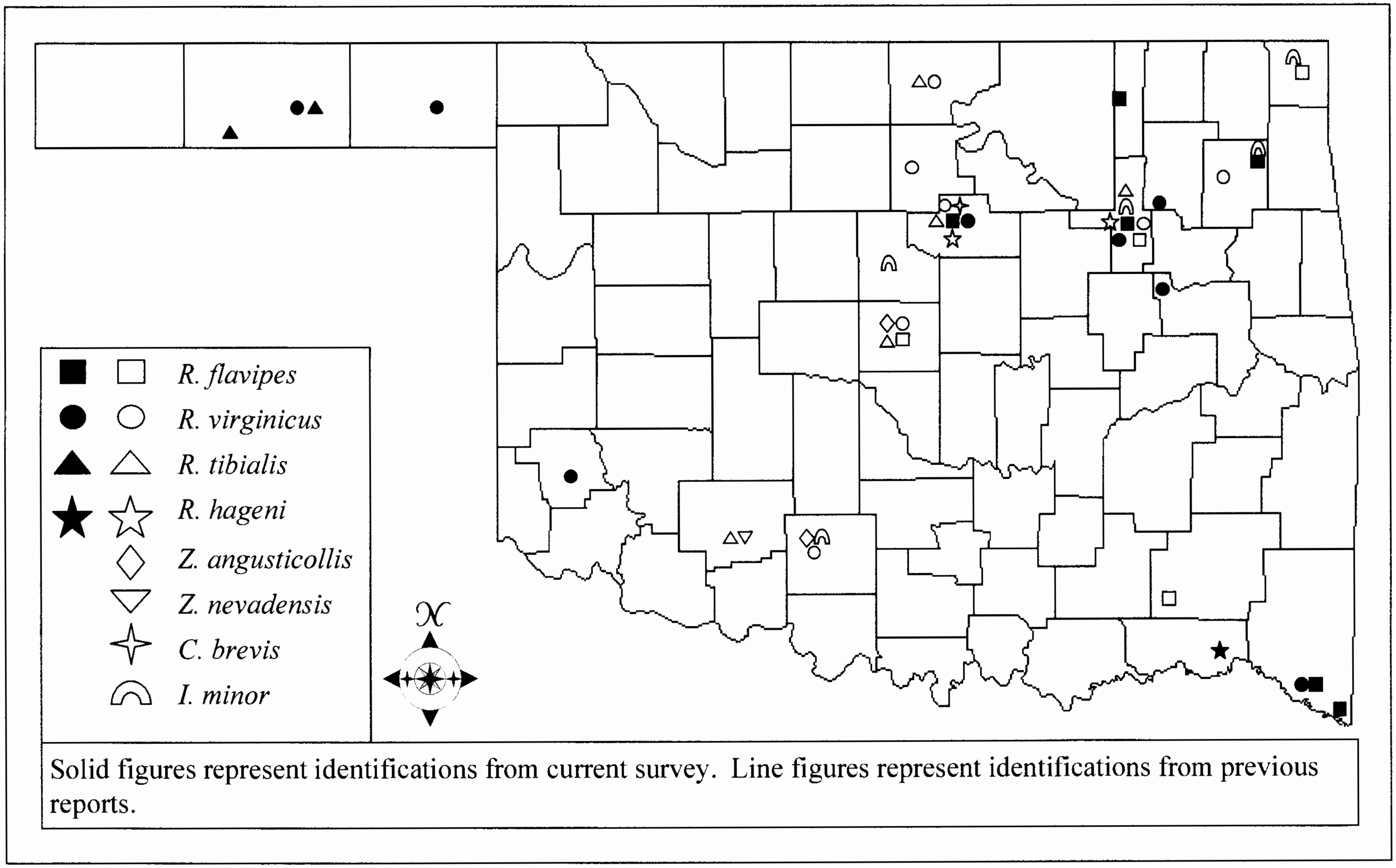

Fig. 3.3. Map of Oklahoma showing locations of identified colonies from the current survey as well as locations of previously reported infestations.

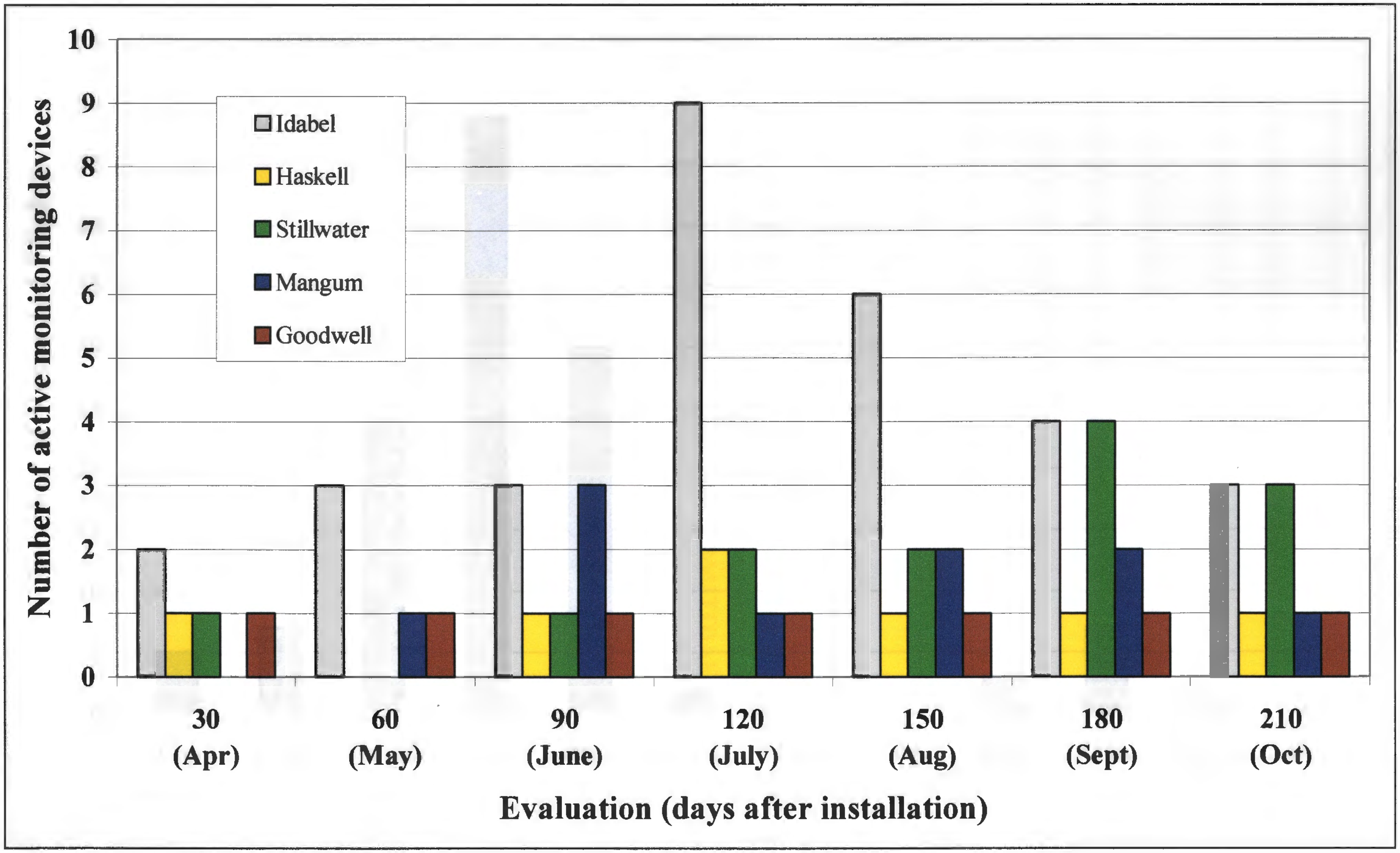

Fig. 3.4. Comparison of termite foraging activity among the five monitoring locations.

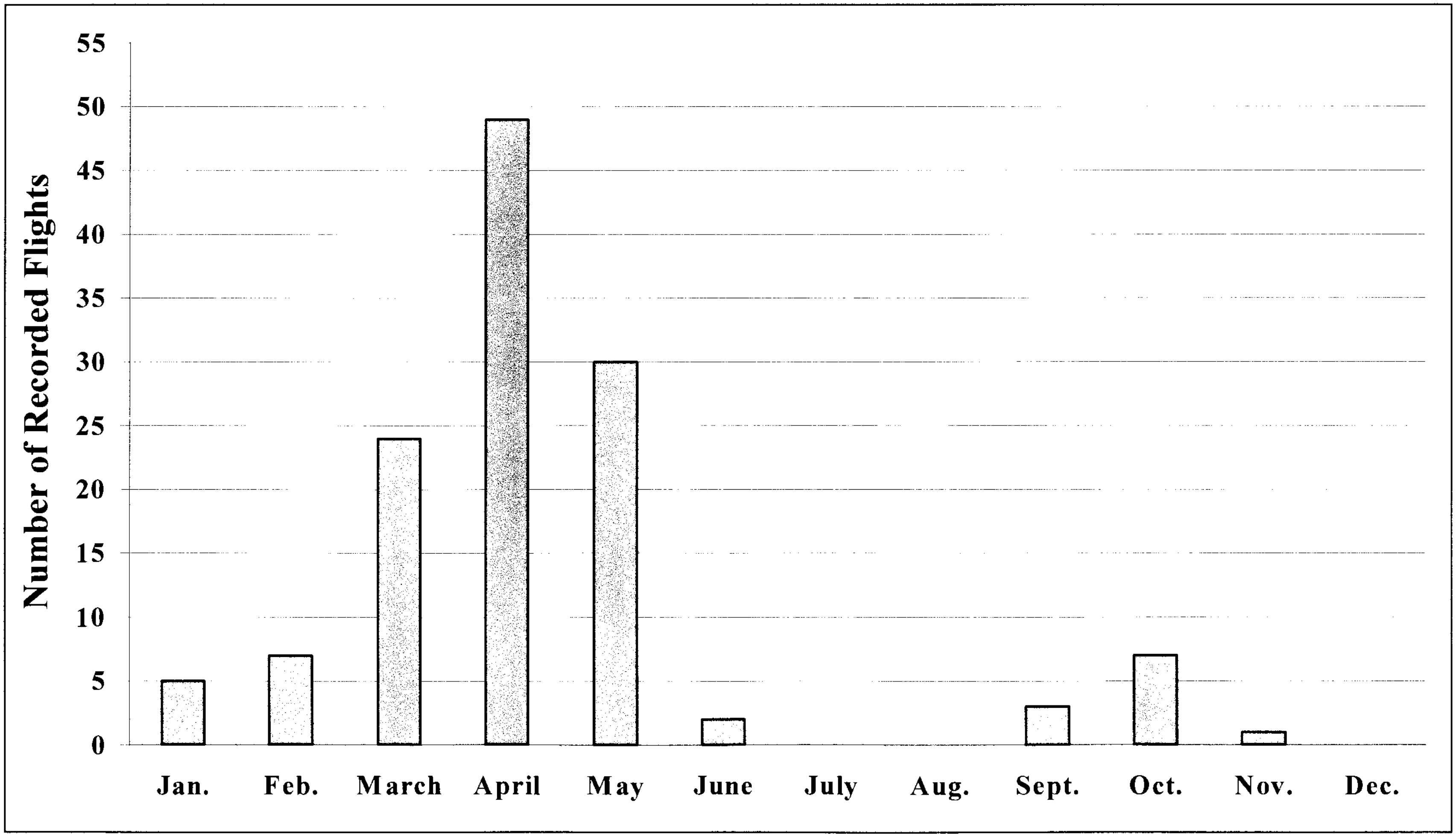

Fig. 3.5. *Reticulitermes* sp. flights based on records in Oklahoma cooperative economic insect survey and detection reports (1955-1992).

CHAPTER IV: INFLUENCE OF ARTIFICIAL GUIDELINES IN SOIL ON CHANNELING FORAGING SUBTERRANEAN TERMITES (ISOPTERA: RHINOTERMITIDAE)

Abstract

This study evaluates a novel technique for improving termite baiting systems. Several variations of Plexiglas® guides were attached to below-ground monitoring stations and placed in the soil to evaluate their influence on foraging termites and bait station finding. The study field was located at Idabel, OK and consisted of six blocks of eight treatments plus a control in a randomized complete block design. The number and size of guides varied between treatments. Monitoring stations without guides were used as controls. The time between installation of monitoring stations and their initial attack by termites ("lag time") as well as the total number of stations that became active during the study period was recorded for each treatment. Statistical analyses indicated that the guides were not effective in decreasing the "lag time" but did increase the number of stations that became active compared to controls ($P = 0.0198$). Sixty to 100% of stations with guides were located and fed upon by termites. The possibility of using such guides in termite baiting schemes is discussed.

Introduction

During their foraging activities in the soil, subterranean termites encounter many naturally occurring barriers or objects such as rocks, outcroppings of rock with various cracks and fissures, changes in soil type and density, water influx, and roots of numerous grasses, plants, and trees. Man-made objects such as concrete walls and foundations, water and utility lines, and large and small wastewater pipes for drainage are found throughout subdivisions, under roads, and generally in any urban area. Termites are known to concentrate their foraging activities in those areas that are most beneficial to their survival and proliferation, and have been shown to exploit both naturally occurring passageways and artificial guides in their search for wood and other cellulose sources of (Pitts-Singer and Forschler 2000).

It is well known that during their foraging activities, termites encounter only a small percentage of commercial bait stations placed into the soil. Haagsma and Bean (1998) placed extensive bait trials on the campus of University of California, Riverside. Their results showed that 21 of 184 bait stations installed were attacked by termites at some time during the study. Similarly, low encounter percentages were found by Su et al. (1993) using wooden stakes placed in the ground in both undeveloped and residential sites. Generally under field conditions, less than 15% of stations placed around a structure are ever found by termites (Lewis et al. 1998). Thus, the toxicant in the stations is not consumed by termites nor spread among colony members. Further, the “lag time” between installation of in-ground bait stations and initial attack by termites can take several weeks or months or longer. These factors as well as difficulties in estimating termite population decline due to baiting has led to mixed reports about the reliability of baits as stand-alone applications, or even as integrated pest management (IPM) tools in a subterranean termite management program (Lewis et al. 1998; Thorne and Forschler 2000; Evans 2001).

The possibility of using artificial guides to direct termites to in-ground bait stations has not been evaluated. If artificial guides decrease the time taken by termites to locate and begin feeding on bait stations or increase the number of bait stations found by foraging termites, then their use may enhance the effectiveness of baits. Directing termites to bait stations could potentially increase the likelihood of attack and ensure that larger numbers of foragers are exposed to the bait. The objective of this study is to investigate the effectiveness of below-ground Plexiglas® guides on channeling foraging termites to centralized bait stations in field environments.

Materials and Methods

Study Site. The study site was located on the Oklahoma State University (OSU) Kiamichi Forestry Products Research Station in McCurtain county, three miles west of Idabel, OK, in the extreme southeastern corner of the state. The site was approximately 0.5 hectares of grassland with a gentle southwest slope at an elevation of about 149m (489ft) (Fig. 4.1a).

Monitoring Stations. A total of fifty-four monitoring stations were constructed from 35.6-cm (14-in) sections of 5.1-cm (2-in) diameter polyvinyl chloride (PVC) pipe (Fig. 4.1b). Six vertical rows of twenty-four 3.6-mm (9/64-in) holes spaced 1.3-cm (1/2-in) apart were drilled along the length of each pipe beginning 1.3-cm (1/2-in) from one end. Each station was fitted with a standard 5.1-cm (2-in) PVC cap and contained an octagonal billet of *Pinus radiata* D. Don. The billets were 31.8-cm (12½-in) in length and had 3.2-mm (1/8-in) deep groves running the length of four sides. An eyebolt was screwed into the top end of each billet. Each station was vertically inserted 30.5-cm (12-in) deep into the soil so that all drill holes were below the soil surface.

Treatments and Blocking. This study consisted of six blocks of eight treatments plus a control each in a randomized complete block design. Each treatment consisted of artificial guides constructed of sections of 6.4-mm (1/4-in)-thick Plexiglas® that were affixed to the monitoring stations (Fig. 4.1c,d). Monitoring stations without guides were used as controls. Stations were spaced 7.6-m (25-ft) apart. The number and size of guides varied among treatments. Treatments of two or three guides at two lengths (0.6-m (2-ft) or 1.2-m (4-ft)) and two depths (15.2-cm (6-in) or 30.5-cm (12-in)) plus a control (no guides) resulted in nine total treatment configurations ($2^3 + 1$ factorial arrangement). Guides were positioned 180° or 90° apart for the two-guide and three-guide treatments, respectively. A map of the study site and treatment randomization is given in Fig. 4.2.

Station Visitation Rates and Data Recorded. Stations were installed on 2 Oct. 2001 and were evaluated weekly through 27 Aug. 2002. Presence or absence of termites or termite activity (e.g., feeding damage and shelter tubes) was noted during each evaluation. The elapsed time to initial infestation ("hit") was recorded for each newly active monitoring station. To discourage abandonment, active monitoring stations were not disturbed.

Statistical Analyses. To compare treatments with controls as well as treatments with treatments for elapsed time to initial "hit", the data were analyzed using PROC MIXED (SAS Institute 1996) with a 0.05 level of significance. Further, data on the number of active stations for control vs. treatments, and treatment vs. treatment contrasts were analyzed using Fisher's Exact Test and PROC FREQ (SAS Institute 1996; $P \leq 0.05$).

Results

Elapsed time to initial "hit" and total number of "hits" for each treatment configuration and that of the control are given in Table 4.1. Blocks two and three were located in a low-lying area of the field site and Block 3 was flooded during much of the study period. Due to flooding and lack of termite activity, block three was not included in data analysis.

Analysis of the time to initial "hit" data indicated no significant differences between any of the guide configurations and the control. Further, no significant differences were found between treatments with three guides compared with those with two guides, or between treatments with larger guides compared with those with smaller guides.

During the study period, only one control station became active (20%). Numbers of active stations for those with some type of artificial guide ranged from three to five (60 – 100%). Results of the Fisher's Exact Test indicated a significant difference in total number of "hits" between stations with guides compared with controls ($P = 0.0198$). However, no differences were found between configurations based on the number or size of artificial guides.

Discussion

Results of the initial "hit" data indicate that the use of artificial guides did not influence the time taken by termites to locate in-ground monitoring stations. However, these results may be influenced by the lack of prior knowledge of termite foraging territories in the study site. If foraging territories are delineated prior to installation, blocking could be done within known territories, possibly yielding different results. Additional studies are needed to evaluate the efficacy of guides in sites where foraging territories have been previously delineated.

Paramount to the success of a termite baiting scheme is the ability of termites to readily locate and feed on the bait. The possibility of using artificial guides to increase the number of stations found by termites is of interest. Increasing the number of bait stations found by termites increases the amount of active ingredient that can be directly exposed to foraging termites, and therefore the chances of successful colony suppression or elimination.

In conclusion, the utilization of artificial guides increased the number of bait stations located and fed upon by foraging termites. However, these guides did not decrease “lag time”. This low percentage of bait finding is a common problem associated with termite baiting schemes, costly for pest control companies, and a source of concern for homeowners (Potter et al. 2001). Some unique difficulties associated with the current study may have affected the results, and some corrective methods to correct them are described herein. Installation of artificial guides is labor intensive but may be beneficial in difficult control situations.

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Table 4.1. Comparison of elapsed time from initial monitoring device installation to first "hit" and total number of "hits" for eight artificial guide configurations and controls.

Treatment	**Number of Guides**	**Guide Configuration (length x depth)**	**Elapsed-time to Initial "Hit"**[a]							**Total Number of "Hits"**
			Block number							
			1	2	3[b]	4	5	6	Means ± SEM	
Control	0	N/A	*	*	–	*	*	21	267 ± 61a	1a
H	2	0.6m x 15.2cm	56	*	–	*	196	7	183 ± 67a	3b
D	2	0.6m x 30.5cm	*	203	–	70	217	35	171 ± 53a	4b
A	2	1.2m x 15.2cm	308	273	–	70	245	35	186 ± 55a	5b
F	2	1.2m x 30.5cm	294	*	–	161	259	252	259 ± 28a	4b
B	3	0.6m x 15.2cm	280	*	–	252	203	217	256 ± 22a	4b
I	3	0.6m x 30.5cm	21	*	–	14	210	203	155 ± 60a	4b
G	3	1.2m x 15.2cm	*	189	–	42	238	14	162 ± 59a	4b
E	3	1.2m x 30.5cm	203	*	–	*	14	14	178 ± 70a	3b

[a] Days

[b] Block 3 was not used in data analysis due to flooding and lack of termite activity.

* Indicates station that never became active during the study. Maximum number of days (329) was used for analysis.

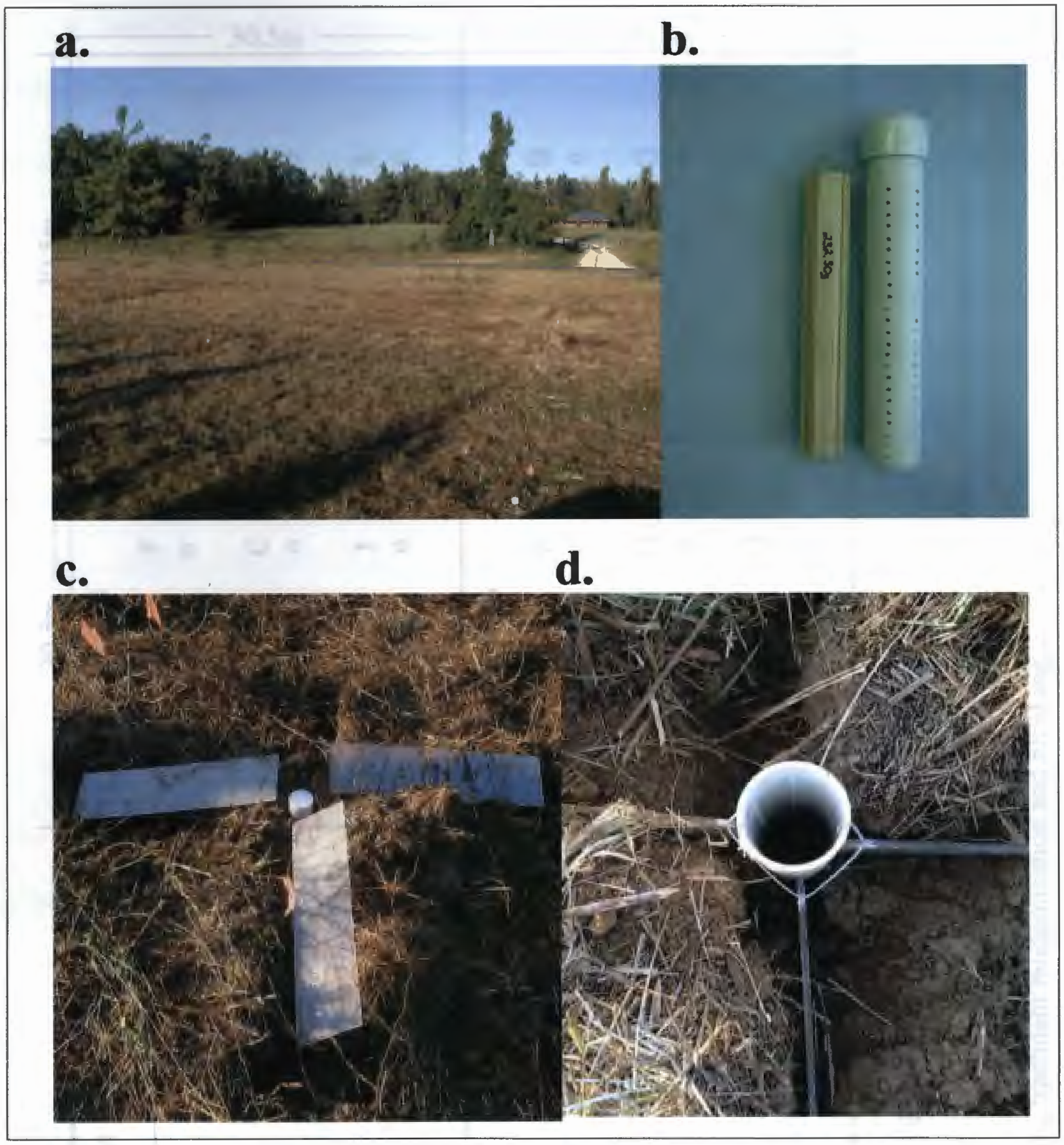
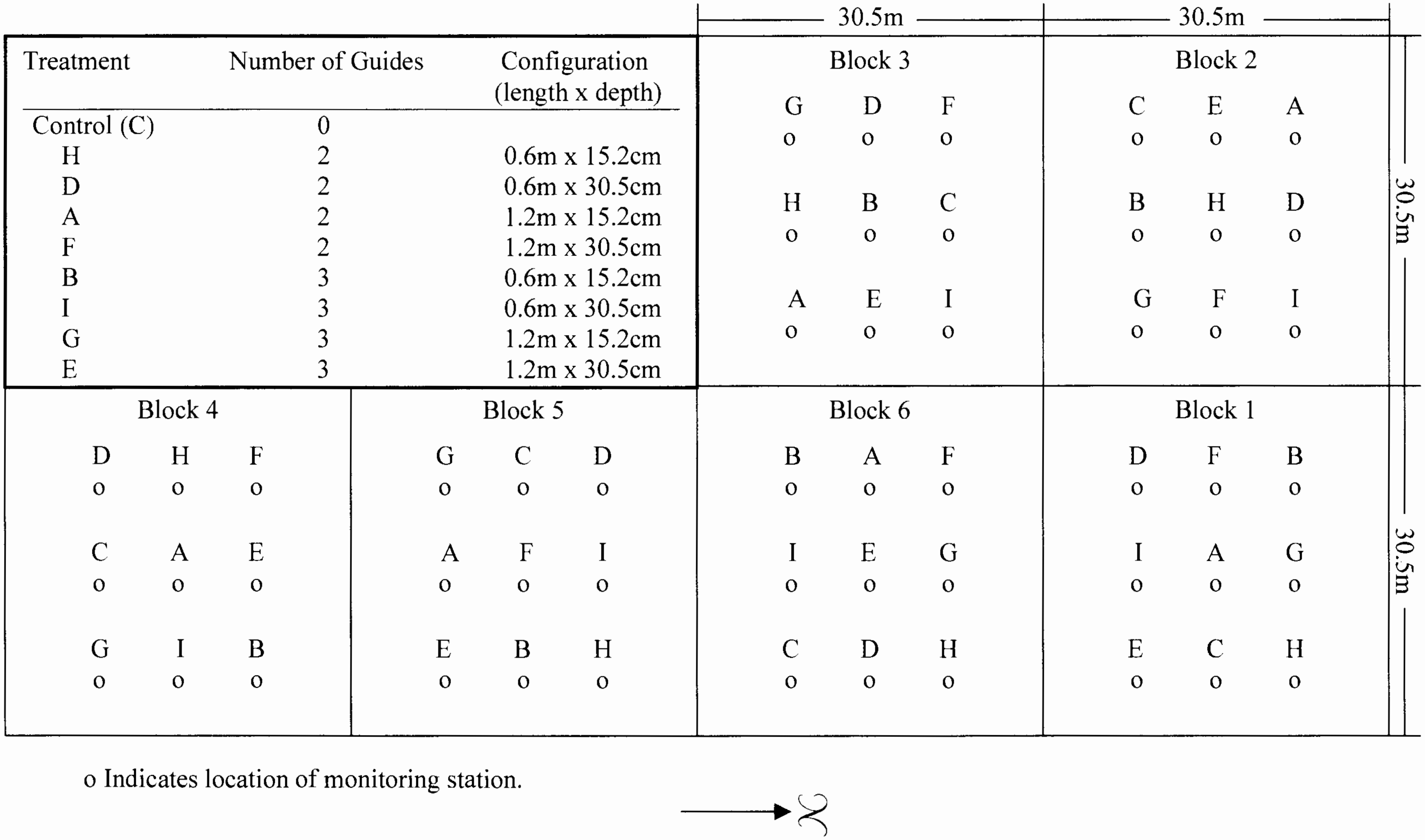


Fig. 4.1. (a) Idabel test site, (b) monitoring station with wooden billet, (c) layout of three-guide configuration, (d) installed three-guide configuration.



Treatment	Number of Guides	Configuration (length x depth)
Control (C)	0	
H	2	0.6m x 15.2cm
D	2	0.6m x 30.5cm
A	2	1.2m x 15.2cm
F	2	1.2m x 30.5cm
B	3	0.6m x 15.2cm
I	3	0.6m x 30.5cm
G	3	1.2m x 15.2cm
E	3	1.2m x 30.5cm

o Indicates location of monitoring station.

Fig. 4.2. Schematic of study site showing treatment randomization and blocking.

CHAPTER V: SUMMARY AND CONCLUSIONS

These studies provide valuable information about the species, distribution, and habits of the termites of Oklahoma. Results of the statewide survey indicate that the range of the tube-building desert termite *Gnathamitermes tubiformans* (Buckley) which has previously only been reported from western Texas, New Mexico, and northern Mexico (Snyder 1954), extends as far north and east as southwestern Oklahoma. Further, the collection of *Reticulitermes virginicus* (Banks) from the panhandle of Oklahoma represents the westernmost report of this species' range. Other species collected in Oklahoma include the dark southern subterranean termite *Reticulitermes flavipes* (Kollar), the arid-land subterranean termite *Reticulitermes tibialis* Banks, and the light southern subterranean termite *Reticulitermes hageni* Banks.

The occasional reports of drywood and dampwood termite infestations noted herein are important for pest control operators and homeowners to note. These termites can be destructive if left untreated. Therefore, it is necessary to be mindful of their possible presence in shipped materials from the southeastern and southern states (drywoods) and western states (drywoods, dampwoods) in which they exist.

Morphological measurements of subterranean termite soldiers revealed a new trait that may aid in the correct identification of species within the genus *Reticulitermes*. Specifically, the ratio of the soldier head capsule length to width consistently separated *R. flavipes* from *R. virginicus*, even in situations where another measurement, pronotal width, would have yielded incorrect identifications. Overlapping head capsule length to width ratios between colonies of *R. virginicus* and *R. flavipes* whose identifications were not confirmed with alate identifications may have two possible explanations. First, this trait, like several others, may not always be consistent at separating these two similar species. The other possibility is that some of the species identifications in the current survey, based solely on soldier morphological measurements using current keys that separate these two species by pronotal width measurements (Hostettler et al. 1995), are inaccurate. Further research is needed to assess the value of this new characteristic in separating soldiers of *R. virginicus* and *R. flavipes*.

Of the 200 monitoring devices installed, only 26 had termite activity at some time during the survey. The greatest amount of activity was recorded the extreme southeast Oklahoma at the Idabel location, with activity in 30% of the monitoring devices. Elevated rainfall, warmer temperatures, and lush vegetation at this site probably account for these elevated termite densities.

In Oklahoma, flights of *Reticulitermes* sp. occur from March through May, with occasional fall flights. Flights of *R. flavipes* occurred one month earlier than those of *R. virginicus* in the fall of 2002. Termite infestations are often originally recognized due to these reproductive flights. Accordingly, there is an increased demand for pest control services during these periods. Therefore, it is important for pest control companies to note the seasonality of termite flights so that they can be ready for the increased demand.

Results of the second study indicate that artificial guides may be useful in directing termites to in-ground monitoring and bait stations. The increased number of "hits" at stations with guides compared with controls support this conclusion. Increasing the number of stations becoming active during a termite baiting procedure both increases the number of locations at which the chemical bait can be introduced to active foraging termites, and increases the number of stations used to evaluate the relative success or failure of a baiting scheme. Increasing the effectiveness of baits and baiting systems could lead to a greater acceptance of their use as an IPM tool in a subterranean termite management program.

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VITA 2

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