PREDICTION of SPRING SUBTERRANEAN TERMITE SWARMS in TEXAS with RELATION to TEMPERATURE and PRECIPITATION

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Abstract We investigated predictive correlations between temperature, precipitation, and springtime subterranean termite swarming in nine Texas cities. Heat units were calculated from December 21 through the date of the initial spring swarms during 1994-1999. Analysis of the heat unit data showed that none of the 54 initial spring swarm events occurred before a minimum of 602 heat units had accumulated, which constituted the minimum heat unit threshold. Analysis of precipitation data indicated a significant correlation between the occurrence of a rainfall event immediately preceding the initial swarm dates. Approximately 90% of the termite swarms occurred within three days of the initial rainfall event following accumulation of at least 602 heat units, irrespective of the amount of that precipitation.

Key Words termites swarm heat units day-degrees

INTRODUCTION

Subterranean termites are the most damaging structural pests in Texas, costing homeowners and businesses millions of dollars each year (Gold et al., 1996). Research has been done on the biology and behavior of these termites, however, there is much to be learned about swarming behavior. In Texas subterranean termites swarm primarily during the spring, and in smaller numbers during the fall (Howell et al., 1987). The purpose of this research was to determine when subterranean termites swarm in the springtime in Texas, with relation to temperature and precipitation.

Many species of subterranean termites are native to North America, can be found throughout much of the United States, and are particularly abundant in the warm and humid climate of the southern states (reviewed in Gold and Jones, 2000). In Texas four main species of subterranean termites in the family Rhinotermitidae are recognized including: *Reticulitermes flavipes* (Kollar); *Reticulitermes hageni* Banks; *Reticulitermes tibialis* Banks; and *Reticulitermes virginicus* Banks (Howell et al., 1987).

Termites are hemimetabolous insects; however, the number of molts and life stages are variable, based on species (Gold and Jones, 2000). The first three larval stages are morphologically similar. Beginning with the fourth instar, subterranean termite larvae differentiate into one of a variety of functional forms. The larvae may differentiate into workers (pseudergates) or nymphs. Development can continue with differentiation into pre-soldiers and then soldiers, or to first-, second- or third-form reproductives. Their development is dependent upon the needs of the colony at a specific point in time (Miller, 1969; Stuart, 1969; Thorne and Forschler, 1998).

Due to the presence of specialized protozoans in their proctodeum, termites are able to digest cellulose, which is vital for survival on a xylophilic diet (Tholen et al., 1997). Not all of the termites in a colony are capable of consuming the crude nutrients offered by this diet. Only the pseudergates, the older larvae, and the nymphs actually consume the raw wood, and they are known as the “primary” feeders. Once consumed, the wood undergoes varying amounts of diges-

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tion within one of the primary feeders before being made available to other members of the colony via trophallaxis.

The soldiers found in subterranean termite colonies generally consume solid stomodeal food, which has been regurgitated by the primary feeders in the colony. The younger larvae and nymphs and reproductives generally receive nourishment from salivary nutrients (Haagsma and Rust, 1995). Consequently, the pseudergates and the older larvae and nymphs are responsible for the structural damage inflicted by subterranean termites (Delaplane and La Fage, 1989; Su and Scheffrahn, 1990).

Subterranean termites are usually first recognized by the public by the above-ground shelter tubes, by damaged wood, or by swarming termites. Swarming is an inherent behavior of alates in the colony for purposes of dispersal and reproduction. Swarming potentially allows the alates to relocate to other areas and establish new colonies. The size of the swarm and, thus, the number of alates that are produced by a colony appear to be directly correlated to the size of the colony (Nutting, 1969).

Alates mature just prior to the initiation of the swarming season, which happens around the same times each year, once or twice a year. It is generally believed that the swarming dates tend to vary if the temperature or precipitation in a particular year differs considerably from the normal average (Scheffrahn et al., 1988).

The general belief is that subterranean termite swarming will occur when the temperature has been within a certain range for a period of time, and a precipitation event occurs near the end of this period. The alates require a certain accumulation of heat units, a measure of energy produced from solar radiation, in order to achieve appropriate growth and maturation. It is common for alates, even though they have reached full maturation, to remain in the colony for a period of time before they actually swarm (Nutting, 1969). Presumably, they are waiting for other environmental clues before they initiate the swarm. One such factor is believed to be precipitation. Studies in south Florida have demonstrated that precipitation is a causal factor for termite swarming. In that study, it was determined that a drywood termite, *Cryptotermes brevis* (Walker) began swarming each year in late spring in direct response to the seasonal spring rains (Minnick, 1973).

Precipitation data require no conversion into other units in order to be correlated with termite swarming. This correlation is simply based on the timing of the precipitation event, and possibly the amount of precipitation. In order to correlate temperature with termite swarming, the average daily temperatures must first be converted to heat units. A heat unit is a measure of energy produced from solar radiation; it is defined as a 1°C difference between a given base temperature (which varies, depending on the subject being studied) and the mean outdoor air temperature on a given day. The base temperature is simply defined as the temperature below which the growth of the termites is halted or drastically decreased (Veeranna and Basalingappa, 1989). For subterranean termites, the aforementioned base temperature is 4°C. The number of heat units produced in a given day then can be calculated using a Fortran program (Ring et al., 1983).

A generally accepted assumption is that accumulated heat units followed by a precipitation event cause the termites to begin swarming. The purpose of this research was to determine if a set of climatic parameters could be used to predict when subterranean termites will swarm each spring in Texas. In order to do this, three types of data needed to be collected and analyzed including: subterranean termite swarm data, daily mean temperatures, and dates and amounts of precipitation.

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MATERIALS and METHODS

Subterranean Termite Swarm Data

Subterranean termite swarming data were collected from the records of Orkin Pest Control Company branch offices in nine different cities in Texas. Each city was selected based upon geographic location, so as to cover different environmental zones. The cities, in order from south to north, based on latitude, were: Corpus Christi (27°46'23"N); San Antonio (29°31'58"N); Houston (29°59'33"N); College Station (30°37'40"N); Waco (31°36'41"N); Tyler (32°18'24"N); Dallas (32°53'52"N); Lubbock (33°40'03"N); and Amarillo (35°13'10"N).

Before visiting the branch offices, it was determined that several types of data were potentially available to help determine the initial spring swarm dates for each of the nine cities. After the initial visit to the first office, it was concluded that the most complete and accessible data set related directly to subterranean termite swarm dates was the time and date of the initial customer calls concerning termite swarming (calls for service), and the dates when the termite treatment service contracts were actually purchased by the customers (service contract renewal dates). The two types of data were obtained by creating and running two different types of computer reports. The first search related the dates that termite service contracts were purchased by customers, and these data were available for the years 1994-99. The second report contained both the date that the customers originally called in concerning termite swarms, and the date that the termite service contracts were sold to those customers. The data from the second data search were available only for the years 1998-99. Both computer reports were programmed to include data from February 1 through May 31 for all available years, a period that covered the entire spring swarm period from mid-winter through late spring.

The computer reports from each city were evaluated, and the termite contracts that had been sold were tallied in order to determine the total number of contracts sold per day from February 1 through May 31 in each city from 1994-99. A computer program was then written to determine the mean two-month period, for each city, with the greatest number of termite service contract sales. This information determined the mean peak swarm period each spring for each of the cities studied.

In the next phase of the research, initial swarm dates for each year were determined by analysis of the number of contracts sold per day from February 1 through May 31 in each city. The initial swarm dates for each city were based on the first day each spring that met two main criteria including: the first day that the number of contracts sold was higher than the most common number of contracts sold per day (greater than zero) during the entire period of time preceding the chosen date; and the number of contracts sold per day continued to be high for approximately one week following the designated initial swarm date. If both of these criteria were met, then that particular day was designated as the initial swarm date. This method was similar to one used in a study of subterranean termites conducted in Louisiana (Henderson, 1996). The researcher calculated the initial swarm dates based on the first week-long trend of an increased number of captured swarming termites, where the numbers captured were greater than any period prior to that week. The first day of that trend was designated as the initial swarm date.

Temperature and Precipitation Data

Temperature and precipitation data were collected from the Office of the State Climatologist on the campus of Texas A&M University in College Station, Texas. These data were collected for each of the nine cities for the years 1993-99. In order to use the temperature data, it was necessary to convert average daily temperatures into heat units (Higley et al., 1986). This conversion was done using the formula: (maximum daily temperature + minimum daily temperature)/2 – base temperature = heat units.

It was necessary to begin the calculation of accumulating heat units from the same initial starting date for each of the nine cities. The baseline date of December 21, the first day of winter, was selected based on the best fit of the data set (Judd and Gardiner, 1997). This date was early enough to allow for a sufficient accumulation of heat units, even for those cities whose initial swarm dates occurred in mid to late winter.

In order to determine the total number of accumulated heat units during this time period, the computer software application Microsoft Excel® was used. The high and low temperatures, as well as the base temperature (always 4°C), for every day from December 21 through the swarm date were manually entered into a Microsoft Excel® spreadsheet. The spreadsheet was programmed with the aforementioned heat unit formula in order to calculate the number of heat units for every day that was entered. As a result, the computer was programmed to add only the positive heat unit values in calculating the total accumulation of heat units from December 21 to the initial swarm date. This procedure was repeated for each of the six years for all nine cities. The average number of accumulated heat units was then calculated for each of the nine cities, as was the average for the entire state of Texas. Once the heat unit totals were determined for each year in each of the cities, the lowest number of accumulated heat units was noted and used as the minimum accumulated heat unit threshold. This was the least number of accumulated heat units necessary for any swarming event to occur. Once this was established, the date upon which the minimum accumulated heat unit threshold was reached was determined for all 54 swarming events included in this study. This minimum heat unit threshold date was then used for further evaluation in terms of precipitation and initial swarm dates.

The precipitation data collected were manually entered into spreadsheets in Microsoft Excel® Precipitation totals were measured from December 21 through the initial swarm date, one month leading up to the swarm date, two weeks leading up to the swarm date, and one week leading up to the swarm date. Statistical analysis was then conducted on the precipitation totals produced during these four time periods, within each city. Individual precipitation events were also analyzed. In particular, the first precipitation event following the minimum heat unit threshold date was determined. The number of days between this precipitation event and the initial swarm date was calculated in order to determine any correlation between this particular precipitation event and swarming activity. In the absence of rain for a period of time, the nearest precipitation event preceding the swarm date was noted. This procedure was repeated for each of the six years in all nine cities. Percentages of swarming events occurring within varying numbers of days following the aforementioned precipitation event were then determined.

Relating Initial Swarm Dates, Temperature, and Precipitation

Initial swarm dates, heat units, and precipitation were analyzed simultaneously in order to determine the correlation among the three. Generalizations about subterranean termite swarming in the springtime in Texas were then made as a result of the correlations among these three factors.

Data Analysis

Statistical testing of the initial swarm dates, accumulated heat units, and precipitation within each city was conducted by using ANOVA (SigmaStat, 1997). Analysis of the median number of heat units for each site was conducted using ANOVA and the Tukey test (SigmaStat, 1997) with paired comparisons.

RESULTS

Subterranean Termite Swarm Data

The average number of contracts sold per day between February 1 and May 31 was determined using the yearly data from 1994-99 for each of the nine Texas cities (Figures 1-9). There was a significant trend for swarming to begin in the southern-most regions of Texas in February, and to progress to the north where swarming was recorded as late as mid-May. By evaluating the numerical data for the two-month period of greatest swarming activity, the mean initial spring swarm date and the extent of the peak warming season for each city was determined (Table 1). Variation for the estimated swarming date was 5.1 days. At least 70% of the total termite service contracts sold for the year occurred within the peak spring swarming season for each of the nine cities.

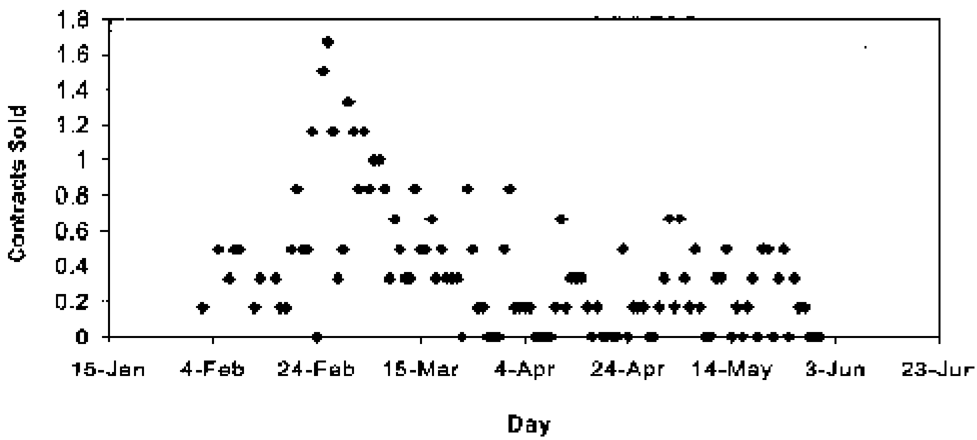

Figure 1. Median number of termite service contracts sold per day from February 1 through May 31, based on data for the years 1994-99, in Corpus Christi, Texas.

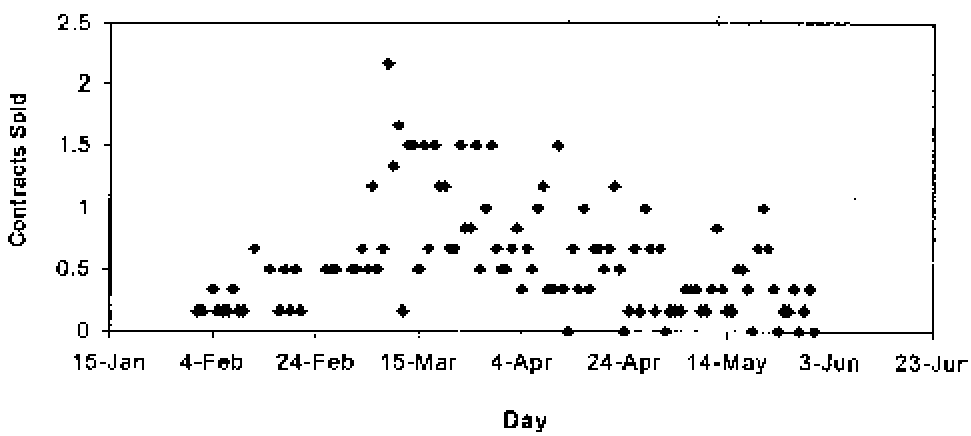

Figure 2. Median number of termite service contracts sold per day from February 1 through May 31, based on data for the years 1994-99, in San Antonio, Texas.

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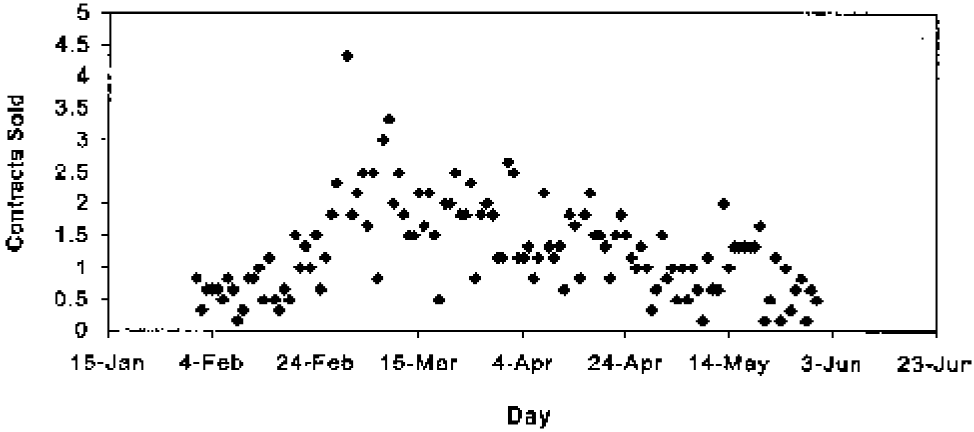

Figure 3. Median number of termite service contracts sold per day from February 1 through May 31, based on data for the years 1994-99, in Houston, Texas.

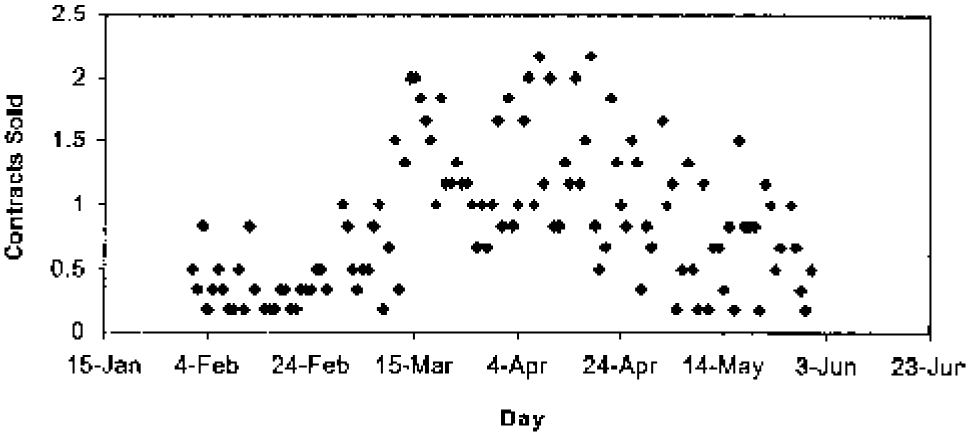

Figure 4. Median number of termite service contracts sold per day from February 1 through May 31, based on data for the years 1994-99, in College Station, Texas.

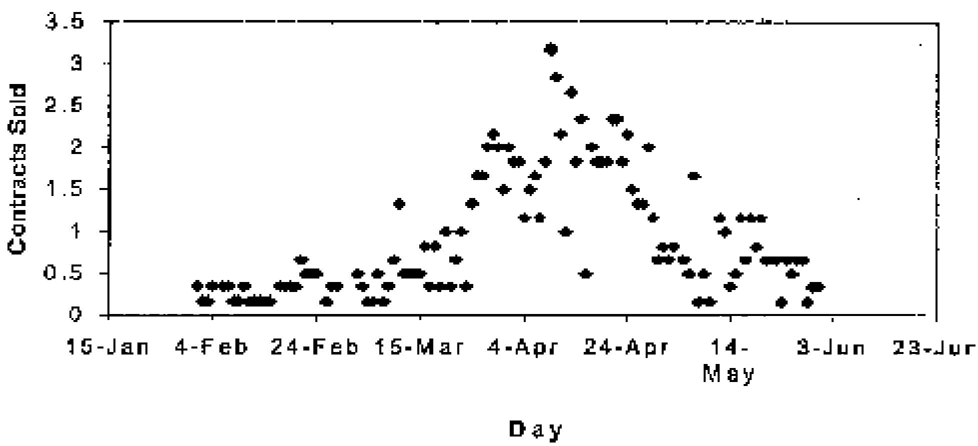

Figure 5. Median number of termite service contracts sold per day from February 1 through May 31, based on data for the years 1994-99, in Waco, Texas.

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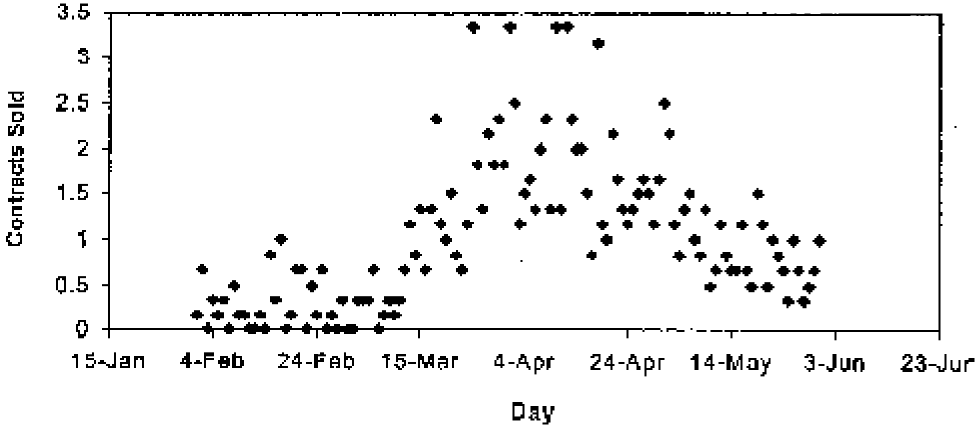

Figure 6. Median number of termite service contracts sold per day from February 1 through May 31, based on data for the years 1994-99, in Tyler, Texas.

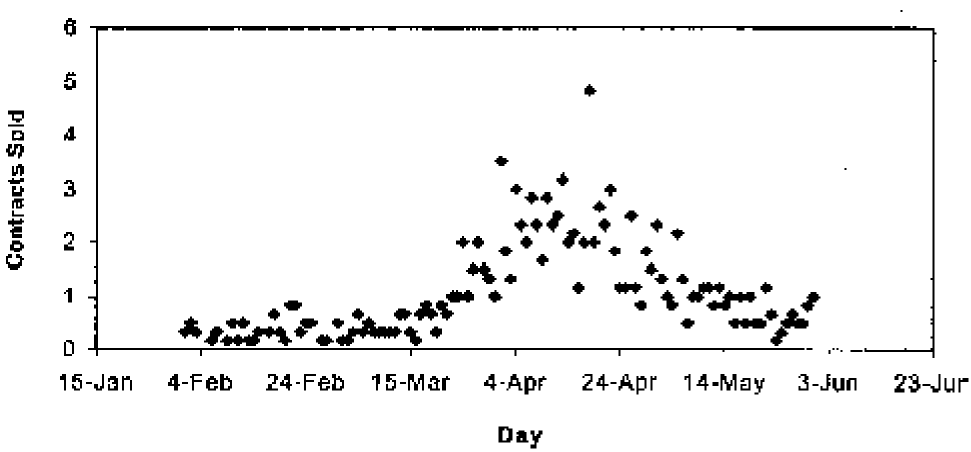

Figure 7. Median number of termite service contracts sold per day from February 1 through May 31, based on data for the years 1994-99, in Dallas, Texas.

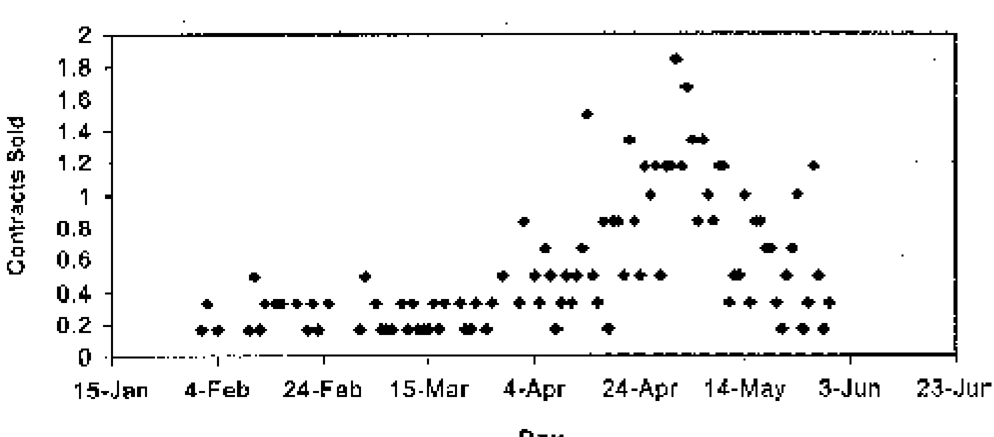

Figure 8. Median number of termite service contracts sold per day from February 1 through May 31, based on data for the years 1994-99, in Lubbock, Texas.

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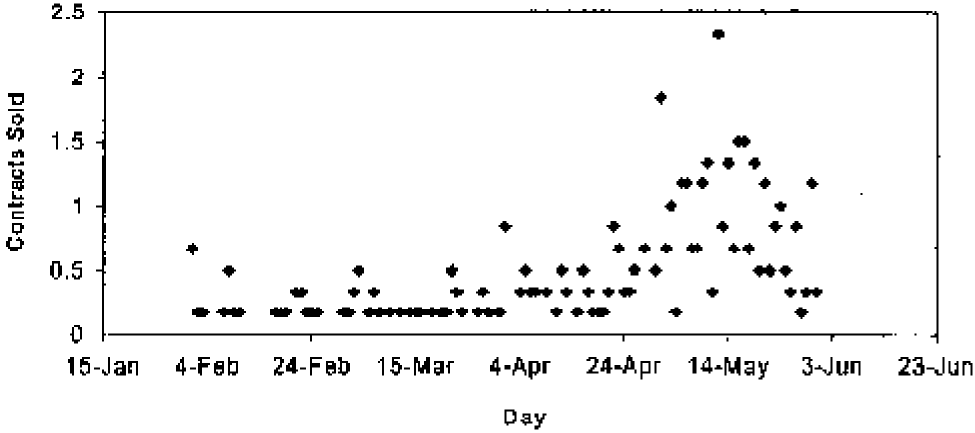

Figure 9. Median number of termite service contracts sold per day from February 1 through May 31, based on data for the years 1994-99, in Amarillo, Texas.

Table 1. Mean initial spring swarm dates, and the respective standard deviations, for nine Texas cities. Additionally, the mean peak spring swarm period, and the percentage of the total annual number of termite service contracts sold were from February 1 through May 31 for the years 1994-99

City	Mean Initial Swarm Date	Standard Deviation (Days)	Peak Swarm Period	% of Total Contracts Sold During Peak Period
Corpus Christi	Feb 23	4.5	Feb. 12 – Apr. 12	72.3
San Antonio	Mar 07	3.0	Mar. 01 – May 01	76.3
Houston	Feb 28	5.5	Feb. 22 – Apr. 22	70.2
College Station	Mar 11	5.8	Mar. 04 – May 04	71.9
Waco	Mar 24	5.8	Mar 15 – May 15	77.4
Tyler	Mar 18	5.2	Mar 13 – May 13	79.6
Dallas	Mar 28	4.3	Mar 21 – May 21	81.2
Lubbock	Apr. 20	6.3	Apr. 01 – Jun. 01	82.0
Amarillo	May 06	5.6	Apr. 01 – Jun. 01	81.2

Temperature Data

All temperature data were successfully converted into heat units for each specific location and swarm season. The means and standard deviations of accumulated heat were determined (Table 2). The results of the one-way ANOVA and Tukey Tests ($p \leq 0.05$) indicated that seven of the nine cites had statistically similar means of accumulated heat units. Houston and Amarillo were significantly different from the other cities, but both cities were statistically similar to each other. The mean of means for the seven cities (excluding Houston and Amarillo) was 669.0± 20.1. The means for Houston and Amarillo were 624.3±15.1. From the data present in Table 2, it was determined that 602 heat units was the minimum threshold for subterranean termites swarming. This minimum threshold was used to determine the approximate date each year that the minimum number of heat units was accumulated (Table 3). These minimum threshold dates were used for further evaluation of the relationships to the precipitation data.

Table 2. Accumulation of heat units from December 21 through the initial swarm date for each year from 1994-99, and the mean and standard deviation for this time period, in each of nine Texas cities

	Number of Accumulated Heat Units (°C)							
	1994	1995	1996	1997	1998	1999	Mean	S. D.
Corpus Christi	690.8	702.1	668.4	669.2	675.7	712.4	686.4 a[1]	19.7
San Antonio	659.5	661.7	645.6	659.7	691.8	673.2	665.2 a	15.7
Houston	641.2	631.3	608.4	610.3	617.8	628.7	622.9 b	12.9
College Station	656.1	687.9	714.0	665.6	667.8	660.8	675.4 a	22.4
Waco	670.7	702.7	648.4	678.4	646.5	665.9	668.8 a	20.9
Tyler	666.1	641.7	685.7	678.1	642.1	652.7	661.1 a	18.6
Dallas	642.9	688.7	691.1	649.3	657.2	678.8	668.0 a	20.9
Lubbock	705.4	654.4	690.2	654.4	639.9	651.9	661.8 a	22.8
Amarillo	616.6	638.2	624.3	651.3	601.8	621.4	625.6 b	17.2

1. Means followed by different letters are significantly different at the $p < 0.05$ (Tukey).

Table 3. Approximate date the minimum heat unit threshold (~602 heat units) was reached each year from 1994-99, and the mean dates for this time period, for each of nine Texas cities

	Date Minimum Heat Unit Threshold Was Reached						Mean
City	1994	1995	1996	1997	1998	1999	Date
Corpus Christi	Feb 18	Feb 23	Feb 20	Feb 20	Feb 16	Feb 11	Feb 18
San Antonio	Mar 05	Mar 02	Mar 03	Mar 07	Feb 28	Feb 25	Mar 02
Houston	Mar 06	Feb 25	Feb 28	Feb 28	Feb 26	Feb 19	Feb 27
College Station	Mar 12	Mar 07	Mar 01	Mar 07	Mar 07	Feb 25	Mar 05
Waco	Mar 24	Mar 19	Mar 25	Mar 20	Mar 24	Mar 07	Mar 19
Tyler	Mar 21	Mar 16	Mar 19	Mar 10	Mar 15	Mar 08	Mar 14
Dallas	Mar 24	Mar 20	Mar 27	Mar 22	Mar 29	Mar 18	Mar 23
Lubbock	Apr 07	Apr 07	Apr 16	Apr 20	Apr 25	Apr 09	Apr 15
Amarillo	May 11	Apr 28	Apr 29	May 05	May 12	Apr 29	May 04

Precipitation Data

The first precipitation event following the minimum threshold date (date accumulated heat units reached at least 602) was analyzed. The number of days between this first precipitation event and the initial swarm date was determined (Table 4). The evaluation of the first significant precipitation event following the minimum heat unit threshold date showed that, out of the 54 total initial swarm dates determined in this study, 13 (24.1%) occurred on the day of the first precipitation event, 26 (48.1%) occurred within one day, 43 (83.3%) occurred within two days, and 49 (90.7%) occurred within three days of the first precipitation event. Precipitation totals were determined for the following time periods: from December 21 to the initial swarm date, one month preceding the swarm date, two weeks preceding swarming, and one week immediately preceding the swarm date. The median totals for each of the categories were then determined for each city (Table 4). Statistical analysis determined that upon individual analysis of the four periods measured within each city, there were no significant correlations based on amount of precipitation.

Relating Initial Swarm Dates, Temperature, and Precipitation

The results of the initial swarm date data, heat unit calculation, and precipitation data were analyzed. Table 5 summarizes the data for each of the 54 swarm events in order to present the

Table 4. Summary of the amount of the first significant precipitation event, following the minimum heat unit threshold date, and the number of days between this precipitation event and the initial swarm date in each of the nine Texas cities

City	Year	Number of days between First Precipitation Event* and Initial Swarm Date	Amount of Precipitation Event (inches)
Corpus Christi	1994	3	0.06
	1995	3	1.05
	1996	21	0.02
	1997	1	0.02
	1998	2	0.65
	1999	2	0.07
San Antonio	1994	0	0.15
	1995	2	0.22
	1996	2	0.02
	1997	2	0.07
	1998	2	0.07
	1999	0	0.01
Houston	1994	0	0.04
	1995	0	0.76
	1996	1	0.53
	1997	2	0.01
	1998	2	1.51
	1999	0	0.29
College Station	1994	1	0.30
	1995	2	0.05
	1996	10	0.02
	1997	1	0.05
	1998	3	0.07
	1999	2	0.02
Waco	1994	2	0.76
	1995	0	0.02
	1996	3	0.71
	1997	1	0.60
	1998	5	0.34
	1999	3	0.97
Tyler	1994	0	0.08
	1995	1	0.12
	1996	0	0.42
	1997	1	1.36
	1998	2	0.02
	1999	2	0.37
Dallas	1994	2	0.34
	1995	0	1.31
	1996	0	0.05
	1997	1	0.67
	1998	2	0.40
	1999	0	0.01

*Following minimum heat (inches) unit threshold date.

Table 4, continued —

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Table 4, *continued*

City	Year	Number of days between First Precipitation Event* and Initial Swarm Date	Amount of Precipitation Event (inches)
Corpus Christi	1994	3	0.06
	1995	3	1.05
Lubbock	1994	0	0.65
	1995	0	0.72
	1996	15	0.08
	1997	2	0.17
	1998	3	0.37
	1999	1	0.05
Amarillo	1994	1	0.16
	1995	1	0.02
	1996	32	0.12
	1997	1	0.01
	1998	3	0.35
	1999	1	2.65

*Following minimum heat (inches) unit threshold date.

following: the number of days between the minimum heat unit threshold date and the initial swarm date, the number of days between the first precipitation event (following the minimum heat unit threshold date) and the initial swarm date, and the total number of accumulated heat units from December 21 through the initial swarm date. The results show a significant correlation between the accumulation of at least the threshold number of heat units coupled with the onset of a rainfall regardless of the amount of that event.

Correlation Between Date Of Customer Call And Sale Of Treatment Contract

Initial customer calls presumably occurred on or very near the date when termites began swarming. It was recognized that there may have been a disparity between the date of the recorded call for service and the date that the service contract was sold. In order to utilize the entire data set available from the Orkin offices in each of the cities, the time between the call for service and sale of the contract was analyzed. It was determined that the time to respond to the call through the sale of a contract was less than one day. Therefore no adjustments had to be made in estimating the actual swarm date for this data set.

DISCUSSION and CONCLUSIONS

Subterranean Termite Swarm Data

Analysis of the subterranean termite swarming data from nine cities in Texas indicated a definite trend for springtime activity. The data presented in Figures 1-9 indicated that the average spring swarm season started in early February in the southernmost cities and extended through the end of May for the most northern cities. Each graph clearly showed a peak period in termite service contract sales, a two-month period during which at least 70% of the total termite service contracts were sold. This would be the expected trend of swarm dates if the termites were swarming in response to accumulations of heat units. This is due to the fact that it takes longer for cities in the northern part of the state to accumulate heat units, due to cooler mean temperatures. These results parallel those in the Florida study where *R. flavipes* and *R. virginicus* were found to have peak swarm periods each spring between February and May. In Florida, *R. flavipes* swarms between late February and mid-March, and *R. virginicus* swarms between early April and mid-May.

Table 5. Relationship between initial swarm dates, heat units, and first significant precipitation events following the minimum heat unit threshold dates, from 1994–1999 for nine Texas cities

City	Year	Minimum Threshold Date	Initial Swarm Date	Total Accumulated Heat Units	Days from Precipitation to Swarm Date
Corpus Christi	1994	Feb. 18	Feb. 24	690.8	3
	1995	Feb. 23	Mar. 03	702.1	3
	1996	Feb. 20	Feb. 23	668.4	21
	1997	Feb. 20	Feb. 24	669.2	1
	1998	Feb. 16	Feb. 21	675.7	2
	1999	Feb. 11	Feb. 19	712.4	2
	Mean	Feb. 18	Feb. 24	688.6	–
San Antonio	1994	Mar. 05	Mar. 09	659.5	0
	1995	Mar. 02	Mar. 09	661.7	2
	1996	Mar. 03	Mar. 06	645.6	2
	1997	Mar. 07	Mar. 10	659.7	2
	1998	Feb. 28	Mar. 09	691.8	2
	1999	Feb. 25	Mar. 02	673.2	0
	Mean	Mar. 02	Mar. 07	665.2	–
Houston	1994	Mar. 06	Mar. 08	641.2	0
	1995	Feb. 25	Feb. 27	631.3	0
	1996	Feb. 28	Mar. 01	608.4	1
	1997	Feb. 28	Feb. 28	610.3	2
	1998	Feb. 26	Feb. 28	617.8	2
	1999	Feb. 19	Feb. 20	628.7	0
	Mean	Feb. 26	Feb. 28	622.9	–
College Station	1994	Mar.12	Mar. 16	656.1	1
	1995	Mar. 07	Mar. 14	687.9	2
	1996	Mar. 01	Mar. 14	714.0	10
	1997	Mar. 07	Mar. 11	665.6	1
	1998	Mar. 07	Mar. 15	667.8	3
	1999	Feb. 25	Mar. 01	660.8	2
	Mean	Mar. 05	Mar. 11	675.4	–
Waco	1994	Mar. 24	Mar. 28	670.7	2
	1995	Mar. 19	Mar. 25	702.7	0
	1996	Mar. 25	Mar. 29	648.4	3
	1997	Mar. 20	Mar. 26	678.4	1
	1998	Mar. 02	Mar. 26	646.5	5
	1999	Mar. 07	Mar. 11	665.9	3
	Mean	Mar. 16	Mar. 24	670.1	–
Tyler	1994	Mar. 21	Mar. 25	666.1	0
	1995	Mar. 16	Mar. 18	641.7	1
	1996	Mar. 19	Mar. 25	685.7	0
	1997	Mar. 10	Mar. 14	678.1	1
	1998	Mar. 15	Mar. 18	642.1	2
	1999	Mar. 08	Mar. 13	652.7	2
	Mean	Mar. 14	Mar. 18	661.1	–

Table 5, continued —

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Table 5, *continued*

City	Year	Minimum Threshold Date	Initial Swarm Date	Total Accumulated Heat Units	Days from Precipitation to Swarm Date
Dallas	1994	Mar. 24	Mar. 28	642.9	2
	1995	Mar. 20	Mar. 25	688.7	0
	1996	Mar. 27	Apr. 04	691.1	0
	1997	Mar. 22	Mar. 26	649.3	1
	1998	Mar. 29	Apr. 01	657.2	2
	1999	Mar. 18	Mar. 24	678.8	0
	Mean	Mar. 23	Mar. 28	668.0	–
Lubbock	1994	Apr. 17	Apr. 22	705.4	0
	1995	Apr. 07	Apr. 12	654.4	0
	1996	Apr. 16	Apr. 20	664.8	15
	1997	Apr. 20	Apr. 24	654.4	2
	1998	Apr. 25	Apr. 29	639.9	3
	1999	Apr. 09	Apr. 14	651.9	1
	Mean	Apr. 15	Apr. 20	661.8	–
Amarillo	1994	May 11	May 12	616.6	1
	1995	Apr. 28	May 01	638.2	1
	1996	Apr. 29	May 01	624.3	32
	1997	May 05	May 09	651.3	1
	1998	May 12	May 12	601.8	3
	1999	Apr. 29	May 01	621.4	1
	Mean	May 04	May 06	625.6	–

These swarms also occurred increasingly later from the coast to the interior of Florida (Scheffrahn et al., 1988). It became apparent that the swarming activity occurred at approximately the same time, within a week, in the individual cites for each of the six years included in the study (Table 3). Again, this points to the influence of environmental factor such as temperature and precipitation that follow an annual cycle. Nutting, (1969) believed that the difference in annual swarm dates was due to variations from normal seasonal medians.

Temperature Data

The results of this research indicated a strong correlation between accumulation of heat units and subterranean termite swarming. The large majority of the 54 swarm events occurred after heat unit accumulations between 640 and 680 day-degrees (Tables 2 and 5). The minimum heat unit threshold was 602, with no swarming activity noted below that level. The concept of tracking heat units through the year appears to have merit in predicting the annual termite swarm. This would have implications in programming advertising to target the best time to start a campaign. It would also be beneficial in anticipating labor needs to provide adequate time to hire and train personnel before the swarm season.

After interpreting the results of this experiment, the minimum heat unit threshold proved to be the single most important climatic factor evaluated. It served as the major temperature-related cue for predicting subterranean termite swarms in Texas. With one single exception, all of the swarming events studied occurred within two weeks of the day that the minimum heat unit threshold was reached. Though it would not be appropriate to assume that the alates achieved maturation at an accumulation of exactly 602 heat units, maturation most likely occurred within a reasonable range of this accumulation total.

In addition to the minimum heat unit threshold, other heat unit accumulations proved to be significant. The statistical comparisons of the mean number of heat units, accumulated between December 21 and the initial swarm date, showed that the means were statistically similar among the majority of the cities (Table 2). Seven of the nine cities studied had statistically similar mean accumulations of heat units prior to the onset of swarming by the termites. Amarillo and Houston were the two cities that were not statistically similar to all of the other cities in this study. This research provided no evidence as to why the mean accumulated heat unit totals of these two cities were statistically different from the other seven cities.

When considering heat unit models, it is important to bear in mind that there are always multiple factors involved. Besides simply having the appropriate accumulation of heat units, for example, it is vital for all required nutrients to be present in adequate amounts in order for the termites to obtain optimal growth and maturity (Higley et al., 1986). Not having appropriate amounts of the required nutrients could, for example, cause delayed maturation. This, in turn, would cause the termites to swarm later in the year, giving the false impression that a higher number of heat units were required in order for these termites to reach maturation.

As determined from data obtained from the Office of the State Climatologist of Texas, all of the cities in this study have unique environments and different climatic patterns, albeit some of them are more different than others. This could certainly account for variations in heat units between the different cities. Evaluation of factors such as these would certainly be useful for future research on subterranean termite swarming in Texas.

In summation, the aforementioned factors should be considered not only when analyzing the cities that did not appear to have statistically similar accumulated heat unit means, but they should also be considered for those cities that did appear to have statistically similar means. It is also important, when interpreting the results of this or any other heat unit study, to determine the purposes for which the heat unit model will be used. In making pest management predictions, estimates within 10% are acceptable (Higley et al., 1986). Without even considering any other causal factors, the mean heat unit values from this study would certainly produce estimates within this range.

Precipitation Data

The results of this research showed that a strong correlation existed between individual precipitation events and initial subterranean termite swarms (Tables 4 and 5). According to this particular set of data, there did not appear to be a correlation with respect to accumulated amounts of precipitation or amounts of individually analyzed precipitation events. No accumulations over any period of time measured, beginning with December 21, showed statistical significance. In addition, when individual precipitation events closely preceding the initial swarm dates were studied, no statistical correlation was found to exist between the amounts of these events. Two similar studies on correlations between precipitation and swarming events produced similar results. It was determined that *Hodotermes mossambicus* Hagen (Darlington et al., 1977) and *Odontotermes obesus* Rambur (Veeranna and Basalingappa, 1989) both swarmed within a short period of the first "seasonal" spring rains in late April, but no correlation was found between the swarming dates and the actual amounts of the precipitation events.

The results of this research documented the importance of a precipitation event closely preceding the initial swarms (Table 5). In particular, the first precipitation event following the minimum heat unit threshold date proved to be statistically significant. Out of the 54 total swarm events analyzed in this study, 49 (91%) occurred within three days of the first significant precipitation event following the minimum heat unit threshold date. A very strong statistical correlation was shown to exist between the initial swarm dates and these particular precipitation events, and these data would seem to emphatically support precipitation as being a causal factor for swarming. In a study done in south Florida, where the occurrence of seasonal spring rain follows a defined pattern from year to year, the results were similar. The occurrence of the first of the late seasonal spring rain events triggered a rapid swarming response by the termites each year of the Florida study (Minnick, 1973). Similarly, a study conducted in Arizona showed that *Amitermes silvestrianus* and *Amitermes wheeleri* both swarmed within a day or two of a precipitation event exceeding 0.01 inches (Nutting, 1969).

Out of the five swarming events in Texas that did not occur within three days of the first precipitation event (Table 5) following the minimum heat unit threshold date, four did not have any closely preceding precipitation events. The nearest preceding precipitation event in any of these four instances occurred one-and-a-half weeks prior to swarming, which was also well before the minimum heat unit threshold date. In addition, each of these four initial swarm events had total accumulations of heat units well in excess of the minimum heat unit threshold (714, 705, 665, and 625 heat units, respectively). These events occurred in four different cities, and each of these accumulations of heat units proved to be one of the highest accumulated heat unit totals for each of the respective cities. These data would seem to indicate that the termites delayed swarming, waiting for a precipitation event, and finally just swarmed after a certain period of time when no precipitation event occurred. There were no statistical correlations between the accumulated heat units of these four events, or the number of days since precipitation last occurred. So it is unclear at exactly what point subterranean termites begin swarming in the absence of a precipitation event, or if a different factor triggers the swarms in the absence of precipitation. A similar study of climatic effects on swarming activity was done on *Reticulitermes lucifugus.* The alates of this species were observed to delay swarming anywhere from four to 50 days, following maturation, in the absence of appropriate humidity levels (Nutting, 1969).

The whole purpose of the alate swarming activity is to relocate, reproduce, and establish new colonies. Subterranean termites build their colonies in the soil, and this remains true even if they are infesting a structure (Su and Scheffrahn, 1990). This is due to the fact that they require certain levels of moisture, which they are able to maintain in their below-ground colonies, in order to survive. It is most likely that termites swarm in response to a precipitation event due to the fact that it causes moistening of the soil, which allows for easier tunneling and provides an already damp environment (Nutting, 1969). It is also likely that the increase in humidity provided some protection from desiccation. From the analysis of the precipitation data in this study, it appeared that precipitation events did evoke a behavioral response in the termites resulting in swarming.

Relating Initial Swarm Dates, Temperature, and Precipitation

The overall results of this research did support the existence of a relationship among accumulations of heat units, precipitation events and the dates of springtime subterranean termite swarming events in Texas. The final summation of the data obtained from this research indicated that, over ninety percent of the time, the initial springtime swarms occurred within three days of the first precipitation event following the minimum heat unit threshold date.

There are several factors that should be considered, however, when analyzing any heat unit models. Certainly other factors, in addition to just heat units and precipitation, played a role in when the termites swarmed. Substrate availability and quality, humidity, barometric pressure, and thermoregulation issues in cases of climatic extremes are all factors that very likely had an effect on when the termites swarmed (Higley et al., 1986). Additionally, it is important to recognize that every population of organisms is unique and has the ability to behave in unique ways. This can even be true of populations on a regional basis as well, and is another factor to consider when evaluating the results of this research (Judd and Gardiner, 1997).

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The starting date for heat unit accumulations in this experiment (December 21), though determined in an acceptable manner through empirical fit of the data, was simply an approximation of best fit. As a result of this, and the other factors which should be considered, the reliability of this heat unit summation as a predictor in other years or areas remains to be validated.

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