DATA ANALYSIS OF THE PATTERN INFORMATION OF THE COLLECTIVE DECISION-MAKING PROCESS IN SUBTERRANEAN TERMITE SPECIES

by

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(Under the Direction of Jaxk Reeves)

ABSTRACT

Data were collected by a bioassay design to study the collective decision-making process of food searching for a subterranean termite species. The movements of termites were recorded by voltage-drop sensors, video-taping, and manual counting. Principal components analysis was applied to separate all the experimental replicates into three groups dependent upon termites' final settlements. Multi-phase regression was conducted to determine the change-points in the process of food searching. The result of the data analyses indicated
two general types of termite behavior. For both of these groups, termites seem to identify the food source quickly, but the movements of termites after finding the food are very different.

INDEX WORDS: Data Analysis; Termites; Collective Decision-Making; Multi-phase regression; Nonlinear Regression; Principal Components Analysis

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A Thesis Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE

ATHENS, GEORGIA

2016

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August 2016

DEDICATION

This thesis is dedicated to my grandmother, Meihua Lv, my parents Mingjiu Huang and Nanfei Xu, and all my family members for their unconditional love and support. I love you all.

ACKNOWLEDGEMENTS

Foremost, I would like to express my sincere gratitude to my advisor, Prof. Jaxk Reeves, for the continuous support of my Master study and research in Statistics, for his patience, motivation, enthusiasm and immense knowledge.

My sincere thanks also go to the rest of my thesis committee: Prof. Brian T. Forschler, and Prof. Daniel Hall, for their encouragement and insightful comments.

In particular, I am grateful to Tae-Young Lee for his very hard work to collect the data used in this study, and his patient explanation to help me understand the entomology behind this study.

TABLE OF CONTENTS

Page

1. Introduction

Eusocial insects are characterized by overlapping generation, division of reproduction and labor, and cooperative brood care. Termites, or previously called “white ants”, are a group of eusocial insects that have recently been classified as eusocial cockroaches. So far, more than 100 genera and approximately 1200 species of termites are known [1]. Each species of termite is typically composed of six castes, commonly referred to as primary reproductive (queen and king), workers, soldiers, larvae, nymphs, and secondary productive. The reproductive caste of a colony includes a fertile female and male, known as the queen and king [2]. The queen of the colony is responsible for egg production for the colony. Worker termites are the majority of the colony, and undertake the most labor within the colony, being responsible for foraging, food storage, brood and nest maintenance [2]. The soldiers are present at a very small proportion of colony (1-2%), and their sole purpose is to defend the colony [3]. In the termite colony, productive tasks are usually performed by primary and secondary productive castes, while nonproductive tasks, which mainly include foraging (searching for new food resources), tunneling, and alarm response, are performed mostly by workers. Foraging process which is about how subterranean termites locate sources of food is not known exactly. Researchers thought that the termites simply divide up the areas around the nest and start to dig a network of tunnels. When they find the food, they recruit other termites to the location of the food and close off the tunnels. The foraging ranges of different termite colonies are varied a lot.

Foraging termites produce a variety of chemicals called pheromones that influence their behavior. These pheromones are basically odors that send messages to other termites in the colony. While tunneling underground, the foraging termites secrete pheromones from their

glands and abdomen and lay down a trail of pheromones. When a food location is found, the odor trail is used to recruit other termites to the food source. However, soil temperature, moisture, compaction, size and quality of the food source will have effects on the intensity of the odor trail.

In this study, Dr. Forschler and his graduate student Tae-Young Lee from the UGA Entomology Department designed a Y-shaped experimental set-up, which is illustrated in Figure 1. This lab set-up consists of three chambers connected with a Y-shaped plastic tubing. The tubing has 5 mm diameter, which is a simulation of termites' tunnels. Each chamber is a cylinder of 3.6 cm height and 5.2 cm diameter and has one 5 mm diameter hole to accept the tubing. The Central chamber contains wet vermiculite substrate; the Food chamber has three 1 cm^3 blocks of wood; and the Empty chamber contains nothing. In front of the entrance to each of the three chambers is a sensor to record the movement of termites. These sensors take a reading once every second, and measure the drop in voltage. If the voltage drop is large enough, the sensor records '1', indicating that something passed it; otherwise it records '0'. The sensor counts are thus a record of the movement activity of termites in this experimental set-up. In addition to the sensor counts which were recorded continuously at the one-second level for 5 days, the total numbers of termites settled in Empty and Food chamber were counted daily and recorded using a six-point scale. At the end of each experiments, the actual number of termites settled in Central, Food and Empty chambers were counted.

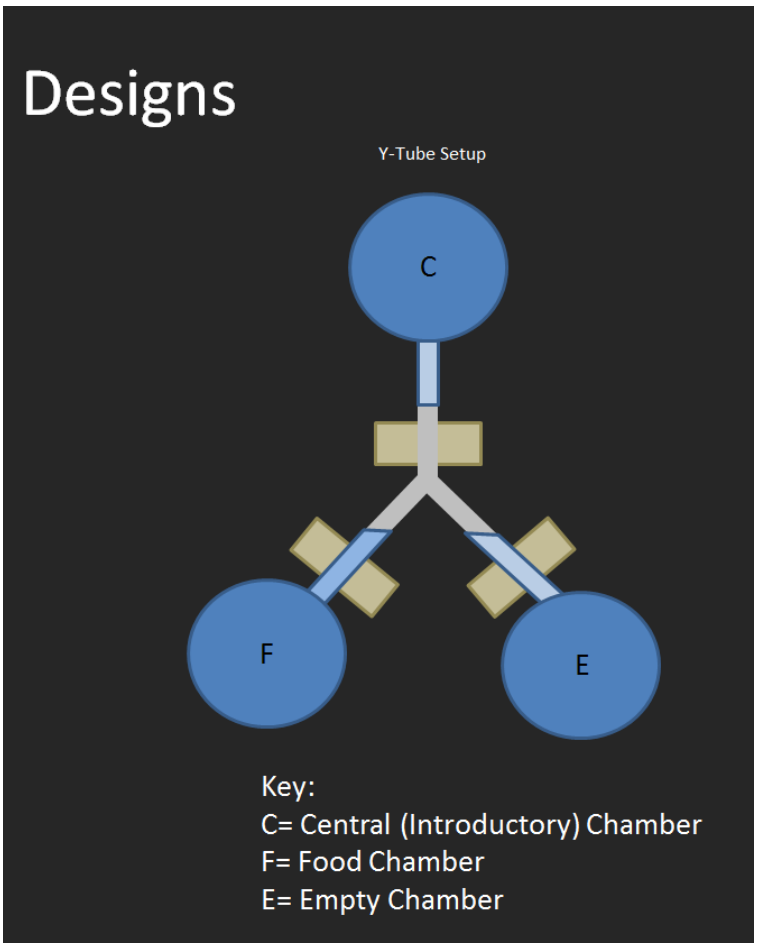

Figure 1. The design of experimental set-up

The primary goal of this study from an entomological viewpoint is to learn more about the following questions:

i. How do termites locate sources of food?

ii. When do the termites make their decision (locate source of food)?

iii. What is the movement of termites after the decision has been made?

As statisticians, we will perform analyses of data available from Dr. Forschler's experiments that may indirectly help to answer these questions. For question (i), we can attempt to examine records of individual termites to see how often individual termites move and when/where they

move. This turns out to be more difficult than it sounds. For question (ii), we can use sensor data to determine when the most movement occurs and in which directions. The data for doing this are much more plentiful than that for answering question (i), but the analysis is not straight-forward. There is also much data available to answer question (iii); doing so in a statistically valid way is a major point of this thesis. It is hoped that the statistical analyses performed on the data from this study will ultimately help researchers to understand how to recruit and manage termites, in order to more effectively protect wood product (e.g. homes and businesses) from damage by termites.

2. Experimental Design

In this study, a total of 36 replicate experiments were conducted. Each replicate was a 5-day experiment conducted in the period from Oct. 2015 to March 2016, with a number of trials run simultaneously. Dr. Forschler's lab had conducted previous versions of this experiment that had lasted for two weeks, but examination of those results made it clear that most colonies were making movement decisions very early, so these replicates were run for five days only. For each replicate experiment, approximately 150 termites (by weight) were randomly scooped from a large collection of termites of the same species which had been cultivated in Dr. Forschler's lab. In addition to these approximately 150 termites, one larger solider termite was added to each artificially created colony to represent the fact that most colonies have about 1% soldiers. It is assumed that most of the other termites selected for each replication are 'workers', although what type of worker is unknown. While the original intention was to have exactly 151 termites in each replicate experiment, the actual number varied between 127 and 167, with a median of 146. For some (7) of the 36 experiments, where individual termites were to be tracked, each termite

was painted with a different colored set of bands so that they could be identified (assuming the video equipment didn't malfunction) at any point when they entered the clear plastic tubing connecting the three chambers. Samples from these videotapes were used, as explained later, both to examine individual termite movement patterns, and also to help convert sensor count numbers into termite movement numbers.

The termites selected for a particular replicate experiment were placed in the Central chamber (with tubing closed) for a 24-hour acclimation period before the experiment was begun. At time zero, the tube was unclamped and termites were free to leave the Central chamber. The termite colony's collective movements were recorded continuously (at the one-second level) via the three sensors for 5 days. In addition, at the end of each day, an approximate count of the number of termites present in the Food and Empty chambers was made by visual inspection. At the end of the 5-day experiment, an exact count of the number of termites in each chamber was made.

Although all 36 replicate experiments each lasted for 5 days, the duration of reliable sensor data for each replicate varied. Seven of the replicates' sensor data were judged to be so poor that data from those experiments were not used at all. For the 29 replicates whose sensor data were used, the first 5240 minutes (about 3.5 days) of sensor data were used in the analyses reported here. This was a time period which was believed to be long enough for meaningful movement patterns to be established, but short enough so that all retained sensor measurements were reliable.

2.1. Sensor Count Data

Three voltage-drop sensors recorded the movement activity of termites in the experimental set-up. These sensors take a reading once every second. If something passes the sensor and triggers it, the sensor records '1', otherwise it records '0'. The distribution of the length of successive 1's is illustrated in the Table 1. About 97% of strings of successive 1's have a length between 1 and 10. Originally, it was believed that each signal of '1' in the sensor data indicated that one termite had passed. However, from understanding the experimental set-up, we know that the sensor counts data definitely have some errors. First, a termite can "sit" on the sensor, which occurs when termites remain in place on the sensor for multiple seconds, causing a sensor to constantly signal that a termite is passing through. Secondly, tubes can be clogged with termites' excrement, which causes sensor to constantly signal as well. Thirdly, termites sometime 'walk' slowly, so that a string of X '1's may represent many fewer than X termites successively passing a sensor. In order to correct the errors of sensor counts data, the videotaped data were compared with sensor count data. The model and correction criteria are discussed in Section 3.

Table 1. The distribution of the length of successive runs of 1s

Length of successive 1s	1	2	3	4	5	6-10	11-100	101-500	500+
Percentage	61.79%	20.61%	6.04%	3.09%	1.83%	3.46%	2.94%	0.228%	0.013%

2.2. Daily and Final Counts Data

As noted earlier, the numbers of termites in each chamber were counted daily in an approximate way and in an exact manner at the end of the experiment. For the approximate count, which was made at the end of each day, a researcher examined the Food and Empty

chambers and visually estimated the number of termites present in each, using the scale shown in Table 2 below. An attempt was made to create three daily time series (one for each chamber) for each replicate by converting these scale values to actual termite values using the mid-point of each scale, and assigning all others to the unobserved Center chamber. However, this proved unsatisfactory, as the true number of termites released per replicate was not known exactly, and, more importantly, because there was just too much uncertainty in the scale values. For most of the replicates, it appeared, to the resolution provided by the scale used for the daily data, that there was little variability between the values shown on days 3, 4, and 5, so the more exact final counts data (which gives the actual number of termites found in Central, Empty and Food chambers) could be used for this purpose. This is discussed more in Section 3.2. However, it should be remembered that even if these final counts are correct and close approximations to where the termites are located towards the end of the experiment, this will give us little information about one of our questions of primary interest: At what time do termites make their collective decision regarding where the food is located?

Table 2. Scale used for daily counts

Scales	0	1	2	3	4	5
Counts	0	0-10	11-20	21-50	51-100	>100

2.3. Videotaped Data

In addition to the almost continuous sensor data (Section 2.1) and the daily and final counts (Section 2.2), there is some videotaped data that is of use. The entire 5-day experiment was videotaped for seven of the 36 replicates (Rep6, Rep15, Rep16, Rep22, Rep26, Rep31, Rep36). Of course, it would be extremely tedious to view the entire 5-day videotapes made for these

replicates, but by sampling judiciously and recording carefully, one can obtain some very useful information about individual termite movements. For each of these replicates, at least 18 (and up to 66, for some replicates) different 15-minute periods were observed, and for each 15-minute period, all termites present were identified (by color code). In the end, this allowed compilation of a record showing the activity level for each termite in the colony (as well as the number which were never observed). This allows one to make some inferences regarding the behavior of the termites in the colony. This is discussed in more detail in Section 3.3 of this thesis.

We made more extensive use of the videotape data to help correct the sensor count record. The sensor count data, at the second level, is simply long strings of zeroes and ones, with zeroes being much more common. We are interested in contiguous strings of '1', called 'blips', since such blips generally indicate termites passing. As Table 1 of Section 2.1 showed, the most common blip is a single '1', with zeroes to either side. One would expect this to mean that one termite passed the sensor, and videotape analysis of the sensors at randomly selected times when a 1-blip occurs show this to be the case – there are very rare instances of two termites passing a sensor simultaneously and being counted as one, but generally a blip of length one represents one termite passing a sensor point. As the blips grow in size, however, the more untenable the "blip length = termite count" hypothesis becomes; this assumption would result in a serious over-count of termite movements. In Section 3.1, we describe how samples of the video-taped data are matched to 'blip' data to develop a model to correct the sensor data so that it more closely resembles the actual count data that would have been observed if one could videotape (and manually record!) the actual number of termites moving past a sensor at each time-point.

3. Preliminary Data Analysis

3.1. Correction of Sensor Counts

As noted previously, the sensor count data are almost surely over-estimates of termite passage. In order to adjust the sensor count data so that they will more closely resemble actual termite counts, the videotaped data for all three sensors from five experimental replications were compared with simultaneous sensor blip data for all blips which occurred during the first hour of observation for these five replicates. In all, this yielded 420 blips, with most being short, and the longest being 95 seconds long. In addition, the videotapes of these five replicate experiments were synchronized to match up with twenty longer-than-100-second blips, so that some data from these rare events could be obtained. For each of these 440 blips, the videotape was synchronized to match the sensor timing, and the actual number of termites passing (Y) was compared to the blip size (X). For example, there were 160 occasions in the observed sample where a sensor was on for exactly X=2 seconds. Closer examination of these 160 events revealed that in 146 of these 160 cases, only one termite had actually passed, and in only 14 had two termites actually passed. Similar drastic reduction is noted when other long-length stretches of consecutive '1' are observed.

It was desired to use these 440 observations to develop a model to predict termites passing (Y) from blip count (X). For small values of X, this is relatively easy to do, since there are many data points available for each level of X. However, for blips of length X=6 or longer, there are less than 5 observations per blip length, and there is at most one observation for blips of length X=15 or longer. We determined that a log-log linear regression model of the form: $\ln(Y) = \beta_0 + \beta_1 \ln(X) + \text{error}$, where Y is the real movement of termites, and X is the length of blips, is appropriate over most of the data range. If it is fit over the complete range of X values, the many

observations at X=1 have too much influence on the fit, so we considered using various lower bounds for the X which will be used in the model. The model selection procedure for fitting this model is shown in Table 3. The first column shows the lower bound of X in used the model (i.e. LB=1 means using all the data, LB=2 means everything except X=1, etc.). From LB=6 onward, the function does not change much, so the model with LB=6 was used to correct blips of length ≥ 6 seconds. A plot of the fit for these 70 points (X ≥ 6) is shown in Appendix Figure A1. For $1 \leq X \leq 5$, since the sample sizes are relatively large for those data points, the mean of the experimental observations from videotaping are used to model the correction. The final criteria that was used to do the correction of sensor counts are summarized in Table 4.

The best model selected in Table 3 is very close to Y=sqrt(X)/2, so that is what was used to correct blip counts (X) that were 6 or larger, as summarized in Table 4. For sensor counts that are larger than 10, since they are present at only 3.2% of the total data, we choose to correct them by bin mid-point. Three examples (X=1, X=2, X=21) illustrating how the sensor count data were corrected are displayed in Table 5. The fractional counts at the second level can't actually have occurred, but when they are summed over 10-minute (600-second) blocks, they do provide a much more accurate count of termites passing sensors than would the uncorrected sensor counts. These corrected counts (at 10-minute intervals) are the primary data used in the analyses of Section 4.

Table 3. Model selection of correction model

LB	TOTN	B0	EXP(B0)	B1	RMSE	RSQR
1	440	0.0024	1.0024	0.1180	1.7110	0.0897
2	292	0.0555	0.9460	0.1780	1.9760	0.0558
3	171	0.2505	0.7784	0.2961	1.5200	0.1707
4	121	0.4224	0.6554	0.3680	1.1810	0.3520
5	87	0.5012	0.6058	0.3908	1.0640	0.4498
6	70	0.7744	0.4610	0.4551	0.8975	0.6147
7	60	0.8974	0.4076	0.4808	0.8846	0.6487

Table 4. The criteria of correction of sensor counts

Sensor Counts	Corrected To
1	1.00
2	1.12
3	1.15
4	1.18
5	1.20
6	1.22
7	1.32
8	1.41
9	1.50
10	1.58
11-20	1.94
21-30	2.50
31-40	2.96
41-50	3.35
51-75	3.97
76-100	4.69
101-150	5.59
151-200	6.61
201-300	7.91
301-500	10.00
501-1000	13.69
1K-5K	22.36
5K-10K	43.30
>10K	871.00

Table 5. Three examples of sensor count before and after correction

Time(secs)	1	2	3	4	5	6	7	…	21	22
X=1 before correction	1	0	0	0	0	0	0	…	0	0
X=1 after correction	1	0	0	0	0	0	0	…	0	0
X=2 before correction	1	1	0	0	0	0	0	…	0	0
X=2 after correction	1	0.12	0	0	0	0	0	…	0	0
X=21 before correction	1	1	1	1	1	1	1	…	1	0
X=21 after correction	1	1	0.5	0	0	0	0	0	0	0

3.2. Analysis of Daily and Final Counts

At the end of the entire experiment, the actual number of termites settled in Central, Empty and Food chambers were counted. The data were organized and are displayed in Table 6. By observing the numbers of termites settled in each chamber (or using principal components analysis [5]), the 36 replicates can be divided into three groups. The termites of Group 1 (Blue) mostly settled in Food chamber (F), a small amount of them settled in Central chamber (C), and very few chose to stay in the Empty chamber (E). The termites of Group 2 (Red) exhibit an opposite behavior to Group 1's termites; they mostly settled in the Empty chamber with very small number in Food chamber and Central chamber. The majority of termites in Group 3 (Green) chose to stay in the Food chamber, but still a reasonable number of termites settled in Empty chamber and Central chamber. The columns of p(F), p(E), and p(C) are proportion of termites in Food, Empty and Central chambers, respectively, at the end of the experiment. From the plot of p(F) versus p(E) in Figure 2, the 36 replicates can clearly be separated into three groups, which are consistent with the groups we defined above. In the following data analysis section, the sensor counts data will be analyzed by examining these three groups separately in order to reveal if the activities of termites from these three groups are significantly different from one another.

Table 6. Final Counts Summary.

Group	Rep	Used	Central	Food	Empty	sum	p(C)	p(F)	p(E)
Group1	RF Y-1	1	7	143	2	152	0.046	0.941	0.013
	RF Y-2	1	3	136	0	139	0.022	0.978	0.000
	RF Y-3	0	19	128	0	147	0.129	0.871	0.000
	RF Y-4	1	3	132	10	145	0.021	0.910	0.069
	RF Y-5	1	5	144	3	152	0.033	0.947	0.020
	RF Y-6	1	11	142	0	153	0.072	0.928	0.000
	RF Y-10	0	17	115	0	132	0.129	0.871	0.000
	RF Y-11	1	61	75	3	139	0.439	0.540	0.022
	RF Y-14	1	46	98	0	144	0.319	0.681	0.000
	RF Y-16	1	32	110	3	145	0.221	0.759	0.021
	RF Y-18	1	38	108	0	146	0.260	0.740	0.000
	RF Y-19	1	21	118	0	139	0.151	0.849	0.000
	RF Y-21	0	57	92	0	149	0.383	0.617	0.000
	RF Y-24	1	11	123	5	139	0.079	0.885	0.036
	RF Y-26	1	15	134	5	154	0.097	0.870	0.032
	RF Y-27	1	8	145	0	153	0.052	0.948	0.000
	RF Y-28	1	2	153	0	155	0.013	0.987	0.000
	RF Y-29	0	5	151	6	162	0.031	0.932	0.037
	RF Y-31	1	0	145	0	145	0.000	1.000	0.000
	RF Y-32	1	26	140	1	167	0.156	0.838	0.006
	RF Y-33	0	5	156	0	161	0.031	0.969	0.000
	RF Y-35	1	11	152	0	163	0.067	0.933	0.000
Group 2	RF Y-7	0	15	0	112	127	0.118	0.000	0.882
	RF Y-22	1	24	44	78	146	0.164	0.301	0.534
	RF Y-34	1	7	3	155	165	0.042	0.018	0.939
Group 3	RF Y-8	1	32	79	27	138	0.232	0.572	0.196
	RF Y-9	1	19	85	35	139	0.137	0.612	0.252
	RF Y-12	1	36	84	21	141	0.255	0.596	0.149
	RF Y-13	1	32	73	33	138	0.232	0.529	0.239
	RF Y-15	1	16	97	32	145	0.110	0.669	0.221
	RF Y-17	1	21	84	50	155	0.135	0.542	0.323
	RF Y-20	1	30	75	37	142	0.211	0.528	0.261
	RF Y-23	1	31	74	29	134	0.231	0.552	0.216
	RF Y-25	1	38	78	21	137	0.277	0.569	0.153
	RF Y-30	0	42	74	42	158	0.266	0.468	0.266
	RF Y-36	1	9	81	59	149	0.060	0.544	0.396

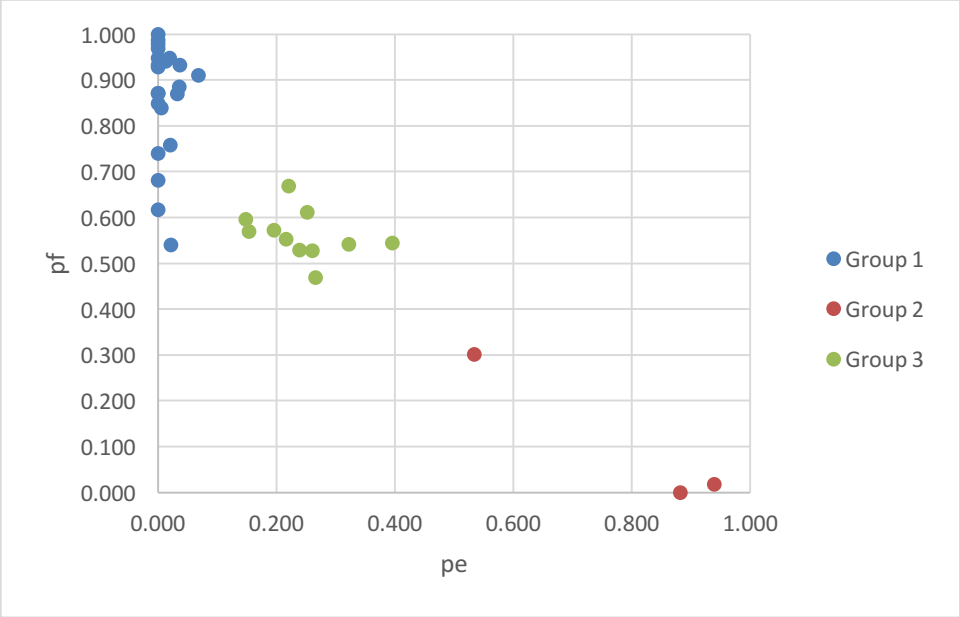

Figure 2. Plot of p(F) versus p(E)

3.3. Analysis of Videotaped Data of Individual Termites

As noted in the previous section, the primary use of videotaping in this research was to develop a model to correct sensor counts so that they more accurately reflect true termite movements. Another use is to study individual termite movements. For seven of the 36 replicate experiments, researcher Tae-young Lee painstakingly painted identifying color codes on each of approximately 150 termites, so that these individual termites could be tracked whenever they travelled through the plastic tubing between the three chambers. However, observing 120 hours' worth of videotape for each of these replicates is a task that even Tae-young couldn't accomplish. Instead, for each replicate, he completely observed the first 2 hours (considered 8 consecutive 15-minute trials) and the first 15 minutes of the next 10 hours, for a complete record of 18 15-minute viewing sessions. (Some replicates were viewed up to 66 times and into the fourth day, but for these analyses, we are considering only the 18 common 15-minute

observation periods which were observed for all 7 replicates during the first 12 hours of the experiment.) For each 15-minute observation period, Tae-young would use the color-coding to record the identities of each termite that was observed and would also record how many sensor triggerings (movements) each observed termite caused during the 15-minute period. This information was accumulated at the end of the 18 observation periods to see how often individual termites were observed, and to learn how many termites were never observed.

Table 7 below summarizes some characteristics of those trials. The color coding is the same as used in Section 4.2, with the four Group 1 replicate experiments in Blue, the one Group 2 replicate experiment in Red, and the two Group 3 replicate experiments in Green. There is certainly nothing in these values to suggest that early behaviors of termites would give much information about the eventual group membership. **N** is the true number of termites in the colony for the given Replicate. **Unique** refers to the number of unique termites that had been observed by the end of the 12th hour. Since the size of each of these colonies is known (see Table 6), it can be seen that proportion of unique termites observed by the 12th hour ranged from 32% (49/155 for R-26) to 92% (141/153 for R-36), with the median being 60% observed. **Appear** is the total number of appearances made, where a termite could receive credit for at most 1 appearance per 15-minute trial. **Movement** is the total number of sensor passes made, where a termite could pass more than one sensor during a given trial appearance. The **Movement/Appearance** ratio seems fairly close to 3.0, so on average, over a 15-minute period, a termite that enters the tubing tends to pass three sensors, or about two per 10-minute period. The **App/N/Trl** value is a measure of the probability that a randomly chosen termite would appear in a randomly chosen 15-minute trial. This statistic varies tremendously across the replicates, from a low of 0.029 for

R-26 to a high of .288 for R-36. The last column. **ODP (ϕ)**, is an over-dispersion parameter obtained if one assumes independent Poisson behavior for each replicate's termites [6].

Even within a replicate, if one attempts to fit a Poisson distribution to the number of appearances per termite, one will observe a huge amount of over-dispersion -- that is, the sample variance is much larger than would be expected given the sample mean. One might think that this could be handled by speculating that the population consists of two groups – 'messenger termites' who venture out frequently and 'domestic termites' who move once from the Center chamber to the Food chamber, but rarely venture out otherwise. Unfortunately, we could find very little evidence for any consistent division like this. The Appearance data for every replication experiment are over-dispersed relative to a Poisson, but the amount of over-dispersion varies tremendously (ϕ=1.40 to 5.45) as shown in the last column of Table 7, and there were no clear divisions of termites into different movement classes.

Table 7. Results from Termite Movement Videotaping Trials over First 12 hours

Rep	Trials	N	Unique	Appear	Movmnt	App/N/Trl	Mov/App.	ODP(ϕ)
R-6	18	153	112	254	655	0.092	2.579	3.89
R-15	18	145	94	201	608	0.077	3.025	1.40
R-16	18	145	93	219	698	0.083	3.187	2.38
R-22	18	146	76	170	423	0.065	2.488	2.58
R-26	18	155	49	80	295	0.029	3.687	5.45
R-31	18	145	89	195	737	0.073	3.779	3.72
R-36	18	153	141	794	2909	0.288	3.663	4.61
Total	**126**	**1042**	**654**	**1913**	**6325**	**0.102**	**3.306**	

4. Final Analysis of Corrected Sensor Counts Data

Although a total of 36 replicates were conducted, the tubing of 7 replicates were found to be severely clogged. Therefore, only 29 replicates of sensor count data are used in the analyses of this section. The identity of the used and non-used replicates can be obtained from the 'Used' column of Table 6 of Section 3.2. We use 17 of the 22 replicates from Group 1, 2 of 3 replicates from Group 2, and 10 of the 11 replicates from Group 3.

As discussed in Section 3.1, the sensor count data have been corrected. The raw data for the sensor counts were recorded in one-second intervals; here they are accumulated into 10-minute intervals. The corrected sensor counts by type (C, F, E) of replicates from three different groups were averaged separately, and plotted in Figure 3, Figure 4, and Figure 5, respectively. Since only two replicates are categorized in Group 2, even after averaging, the plot is still very noisy. Nonetheless, it appears more like Group 3 than Group 1, so in the following analyses, replicates from Group 2 and Group 3 are combined into one group called Group (2,3) as illustrated in Figure 6. The averaged sensor counts of Group 1 and Group (2, 3) are analyzed in the following sections.

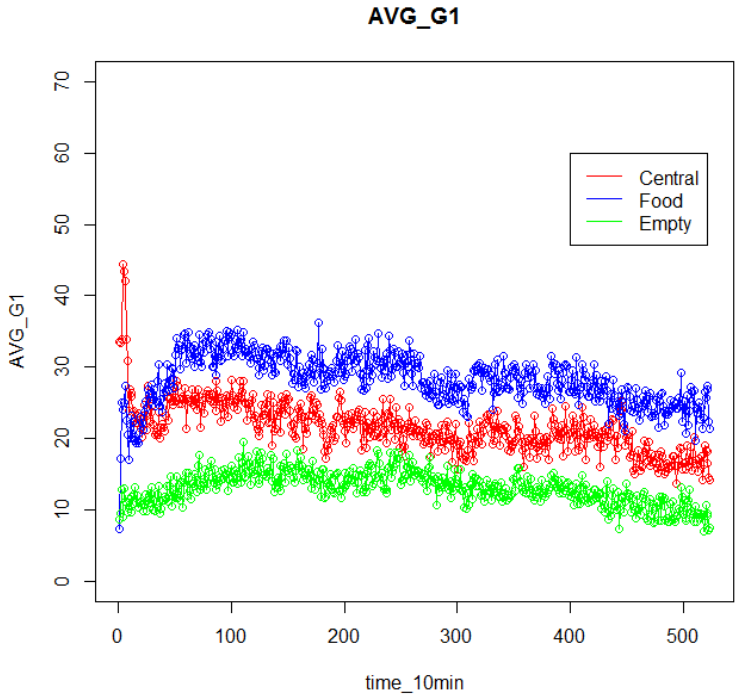

Figure 3. Plot of counts averaged over replicates from Group 1 versus time by sensor

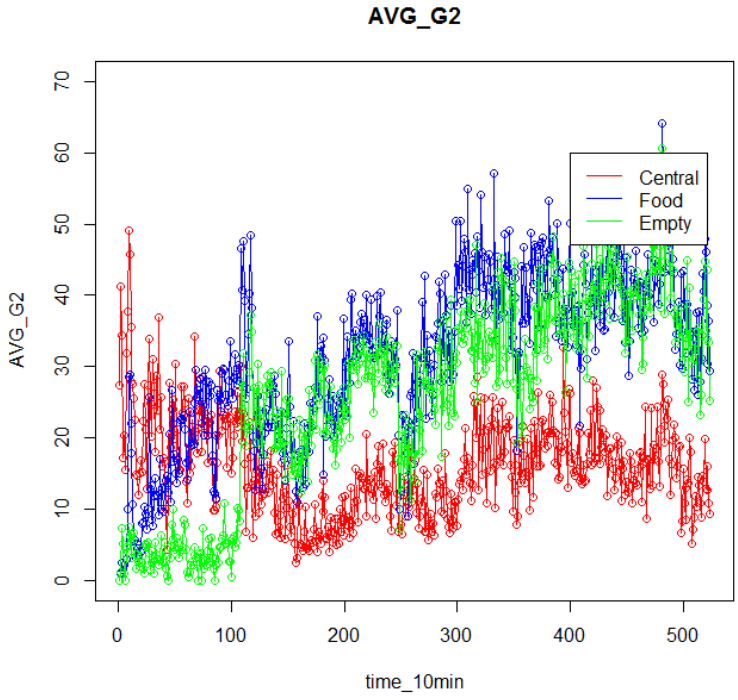

Figure 4. Plot of counts averaged over replicates from Group 2 versus time by sensor

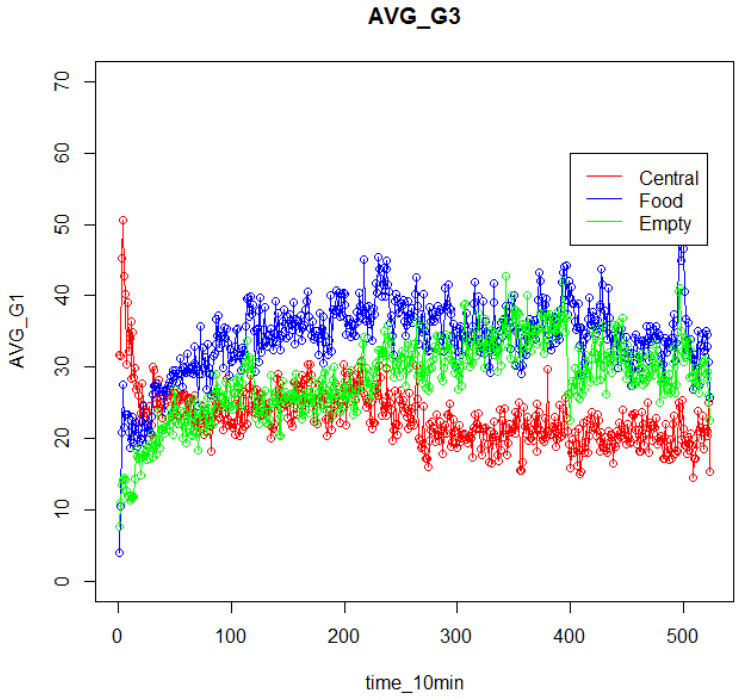

Figure 5. Plot of counts averaged over replicates from Group 3 versus time by sensor

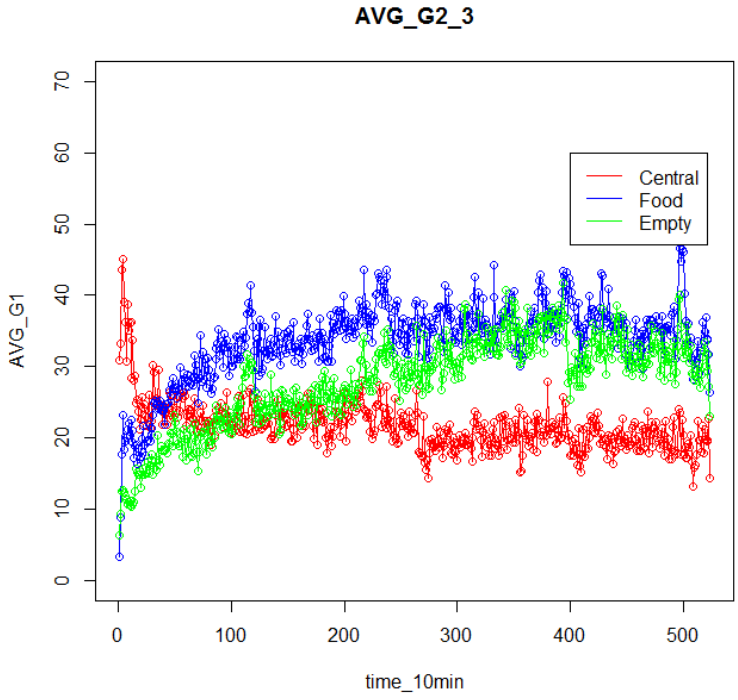

Figure 6. Plot of counts averaged over replicates from Group 2, 3 versus time by sensor

4.1. Analysis of Total Sensor Counts

The total counts of three sensor types (C, F, E) were summed and their average were plotted by group in Figure 7. From 0 to about 1000 min, the mean total sensor counts for Group 1 and Group (2, 3) behave very similarly. However, after approximately 1000 min, the mean total sensor counts of Group (2, 3) become substantially larger than those of Group 1, which means the mean activity level of termites in Group (2, 3) are much higher than termites in Group 1. Moreover, the mean total counts of Group (2, 3) has an increasing trend, whereas the mean total counts of Group 1 continue to decline until the end of the 3.5-day observation period.

One concern with Figure 7 and the plots presented in Section 4.1 is that they are averages over the 17 and 12 replicates in Group 1 and Group (2,3) respectively. The means of the two groups in Figure 7 appear to diverge very sharply after about 1000 minutes, but from this plot, we don't really know how the individual replicates behave. To investigate this further, we created Figure 8, which plots smoothed splines with 10 degrees of freedom [6] fitted to the total counts, for each of the 29 replicates, with Group 1 shown in red and Group 2 shown in blue. As can be noted even with the smoothed splines, there is much variability, but the blue Group (2,3) does tend to exceed the red Group 1 fairly consistently in the second half of the observation period.

One might wonder if there is enough statistical evidence to state that Group 1's mean total is significantly less than Group (2,3)'s mean total. For a fixed time-point (i), this is an easy enough question to answer, as one could perform a two-sample t-test (with $n_1=17$, $n_2=12$) of the form below:

Null hypothesis: $\mu_1=\mu_2$; Alternative hypothesis: $\mu_1<\mu_2$ (one-tailed).

Thus, we calculate the t-statistic:

$$t = \frac{\overline{y_1} - \overline{y_2}}{S_P\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}}$$

where $\overline{y_1}$, $\overline{y_2}$ are the means of total counts observed at time-point i, and S_P is the pooled standard deviation, n_1 is the sample size of Group 1 (17), and n_2 is the sample size of Group 2 (12). Figure 9 below plots the t-statistics for i=1,2…,524, along with the 1-tailed α=0.05 significance value ($t_{27,0.05}$= -1.7). From this, we can see that after about time=2500 minutes, the t-statistics would consistently find the significant difference shown. We are not attempting to perform an overall t-test of the hypothesis above, since the result is not constant and because the individual t-tests are dependent, but this gives some fairly convincing idea of when statistically significant differences between the two groups could be declared.

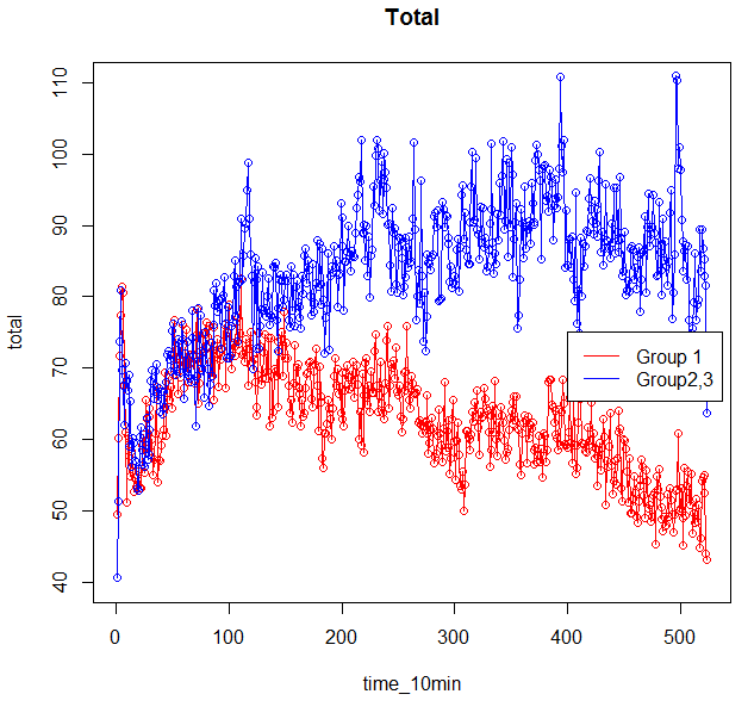

Figure 7. Plot of average total counts total by Group versus time

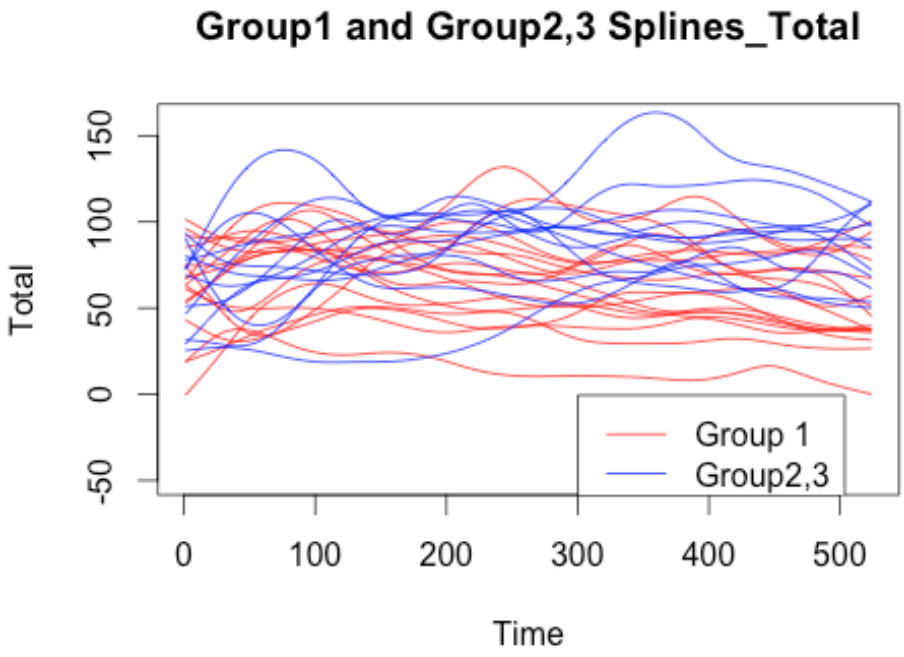

Figure 8. Plot of smoothed splines of Total counts for 29 individual reps over time

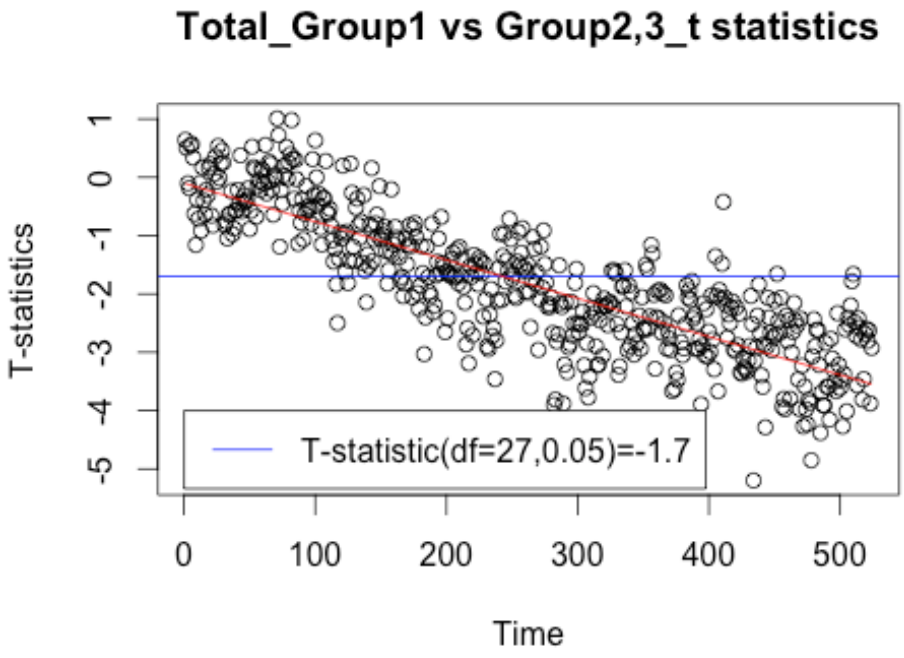

Figure 9. Plot of t-statistics of total sensor counts of (G1-G2,3) over time

4.2. Analysis of Sensor Counts by Types

The averaged corrected sensor count data from Group 1 and Group (2,3) were analyzed separately by sensor types (Central, Food, Empty). From the scatter plot of sensor count versus time in Figure 3 (Group 1) and Figure 6 (Group 2,3), we see that they both illustrate that the change in sensor counts over the entire experimental period appears to consist of three or four stages, and that the behavior over each stage is approximately linear. Therefore, in the following analyses, a nonlinear regression fitting technique was applied to find the "change-points" between each stage and to fit a connecting linear trend for each stage. Note that these are not traditional change-points at which we *a priori* believe that change has occurred. Rather, they are more like 'knots' in a non-parametric fit connected in a continuous way by lines. A more precise name for the fitting performed in this section is multi-phase (M-P) regression. The number of knots (2 or 3) were pre-determined by visual inspection of the data, and the fits were obtained using PROC NLIN in SAS [7], assuming independent homoscedastic errors. These latter two assumptions are questionable at best; the purpose here is simply to obtain rough depictions of the average behavior of the sensor counts by group. This allows us to explore the relationship between corrected sensor counts and time for each stage. These multi-phase regressions were conducted separately for each sensor type within each of the two groups. Time is measured in 10-minute intervals, so the X-variable in these analyses ranges from 1 to 524. The Y-variable is the average (over the 17 or 12 replications comprising Group 1 or Group (2,3), respectively) of the corrected sensor counts for the 10-minute interval on the indicated sensor (C, F, E).

Group 1: The results of multi-phase regressions applied to averaged corrected Central sensor counts for Group 1 are displayed in Table 8 and Figure 10. For this plot, there appear to be three segments, so two change-points are estimated. Initially, the sensor counts increase very quickly; with the first change-point estimated to occur at 53 minutes, when the expected sensor count reaches it maximum expected value of about 45 (over a 10-minute period). This represents the peak of movement of termites out of the Central chamber. At that point, the corrected sensor counts begin to drop rapidly until they reach a level of about 25 per 10-minute period at the second change-point, around 89 minutes after the beginning of the experiment. From that point on, the average 10-minute sensor count tends to decline at a very low rate (.015 per 10 minutes), so that it is around 17 at the end of the observation period (5240 minutes). Since the sensor counts reveal the average activity of termites, the average activity of the termites was very high at the beginning of the experiment, which can be explained by the fact that many termites were leaving the Central chamber during the first hour. After about 89 min, the activity of the termites around the Central chamber dropped back to 25 counts/10 min, and gradually decreased to approximately 17 counts/10 min. It is possible that these results mean that almost all termites moved out of the Central chamber during the first 90 minutes, and the other counts after this represent 'scout termites' who, with decreasing regularity, visit the original nesting spot. It is also possible that many of the termites move during the first 90 minutes, but that the others straggle out over the remaining time – these average activity level analyses can't resolve which, if either, of the above two suggested scenarios is correct.

Table 8. M-P regression estimates for averaged counts for Central sensor -- Group 1

Parameter	Estimate	Approx Std Error	Approximate 95% Confidence Limits	
CP1	5.3387	0.3740	4.6040	6.0734
CP2	8.8747	0.5355	7.8227	9.9266
beta0	28.6034	2.1545	24.3708	32.8360
beta1	3.0440	0.6496	1.7678	4.3202
beta2	-5.5718	1.4526	-8.4254	-2.7182
beta3	-0.0149	0.000607	-0.0161	-0.0137

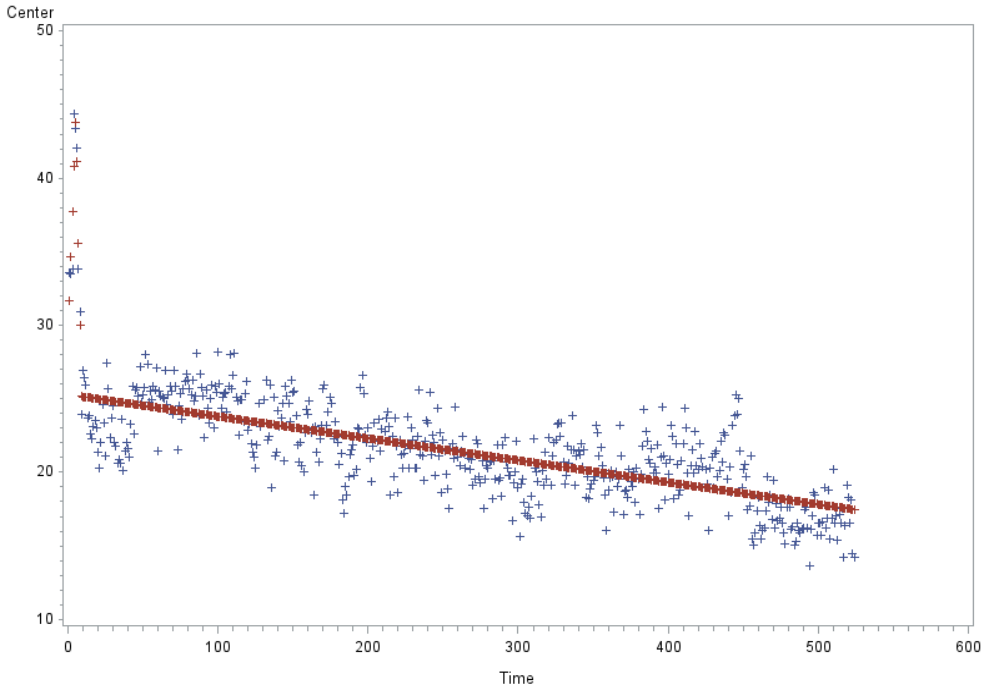

Figure 10. Plot & M-P regressions of average counts vs time for Central sensor-- Group 1

The results of the multi-phase regressions for the Food sensor counts of Group 1 are displayed in Table 9 and Figure 11. In all, 4 segments and 3 change-points are determined for the change of Food sensor counts over time. Initially, the average corrected sensor count has a peak of 27 counts/10 minutes at about 30 minutes after the start of the experiment. This first change-point is close to the first peak of the Central sensor counts. Then, the average Food sensor count drops back to about 19 counts/10 mins at the 90-minute mark. Up to this point, the behavior of

the Food sensor counts is similar to that of the Central sensor counts, although the level is lower at both the peak (27 vs 45) and after the fall (19 vs 25). However, after the second change-point, the activity pattern changes drastically, as the average corrected Food sensor counts next increase from about 19 per 10 min to about 33 per 10 min at about 590 minutes. From that point on, the rate of average termite activity at the Food sensor begins to decrease gradually to about 24 counts/10 mins at the end of the observation period. Although the rate of decrease over this last period is 22% greater than the rate of decrease over this time period for the Central sensor, the overall average Food sensor corrected count is still much larger over this period (falling from 33 to 24) than the average Central sensor corrected count (falling from 24 to 17).

The results of the multi-phase regressions for the average corrected Empty sensor counts of Group 1 are shown in Table 10 and Figure 12. As was the case with the Food chamber sensor, the analysis here finds 4 segments and 3 change-points. The first two change-points for the Empty sensor are at 30 minutes and 310 minutes, respectively. We observe peak activity at both the Central and Food sensors at approximately 30-50 minutes. For the Empty chamber, there is no obvious peak at 30 minutes, but there may be a change in slope after a peak of 11 counts/10 mins was observed. After that, the rate increases to about 11.5 per 10 minutes at 310 minutes before rising to a maximum of about 16 at 1154 minutes. From there, the activity deceases at a similar rate as for the Food chamber sensor, so that it about 10 per 10 minutes at the end of the observation period. Thus, over the last 90% of the observation period, the average corrected Empty sensor counts are about 7 to 8 lower per 10-minute period than the Central counts, which are a similar amount below the Food sensor counts. Most likely, this means that at the very beginning of the experiment, when termites from Group 1 colonies begin to leave the Central chamber, most of these termites go to the Food chamber rather than to the Empty chamber. As

time goes on, the general decrease of activity could mean that most Group 1 termites are not moving much, staying near the Food chamber, with a few occasionally living at or visiting the other two chambers, with visits to the Central chamber being more common than visits to the Empty chamber.

Table 9. M-P regression estimates for averaged counts for Food sensor -- Group 1

Parameter	Estimate	Approx Std Error	Approximate 95% Confidence Limits	
CP1	2.9789	0.4153	2.1631	3.7947
CP2	9.0000	1.0109	7.0140	10.9860
CP3	59.0071	2.0494	54.9809	63.0333
beta0	-2.4258	4.4001	-11.0701	6.2185
beta1	9.7782	2.7829	4.3110	15.2453
beta2	-1.1754	0.3719	-1.9060	-0.4448
beta3	0.2639	0.0193	0.2260	0.3018
beta4	-0.0182	0.000680	-0.0195	-0.0168

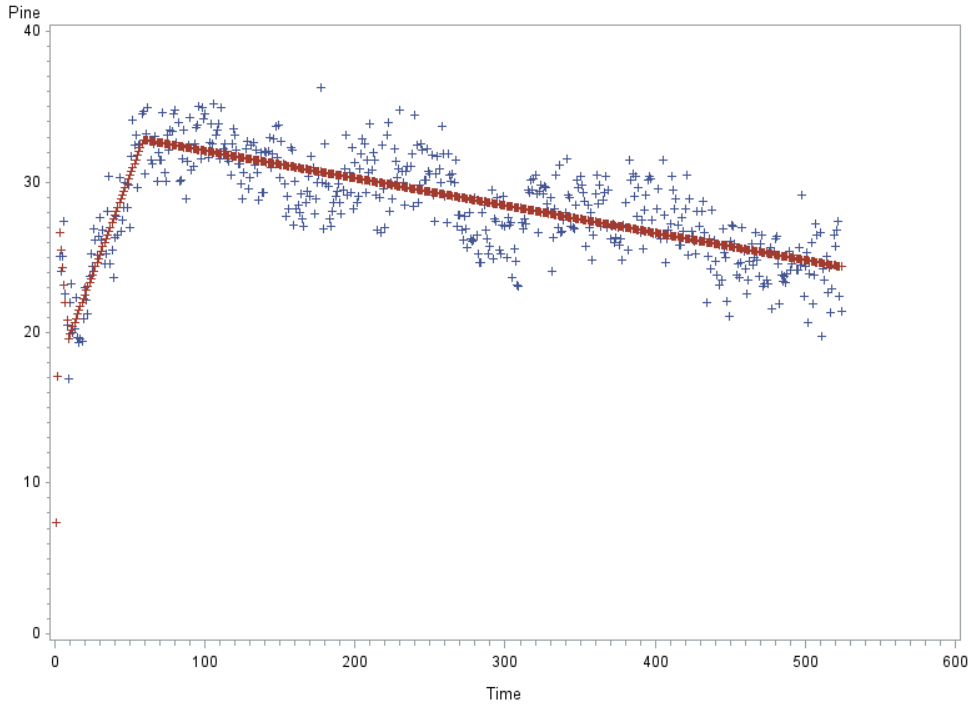

Figure 11. Plot & M-P regressions of average counts vs time for Food sensor-- Group 1.

Table 10. M-P regression estimates for averaged counts for Empty sensor -- Group 1

Parameter	Estimate	Approx Std Error	Approximate 95% Confidence Limits	
CP1	3.0000	2.7837	-2.4688	8.4687
CP2	31.0041	16.7225	-1.8485	63.8566
CP3	115.4	5.0443	105.5	125.3
beta0	7.2813	3.2938	0.8105	13.7522
beta1	1.2163	2.0832	-2.8762	5.3089
beta2	0.0177	0.0327	-0.0465	0.0820
beta3	0.0551	0.00663	0.0420	0.0681
beta4	-0.0148	0.000617	-0.0160	-0.0136

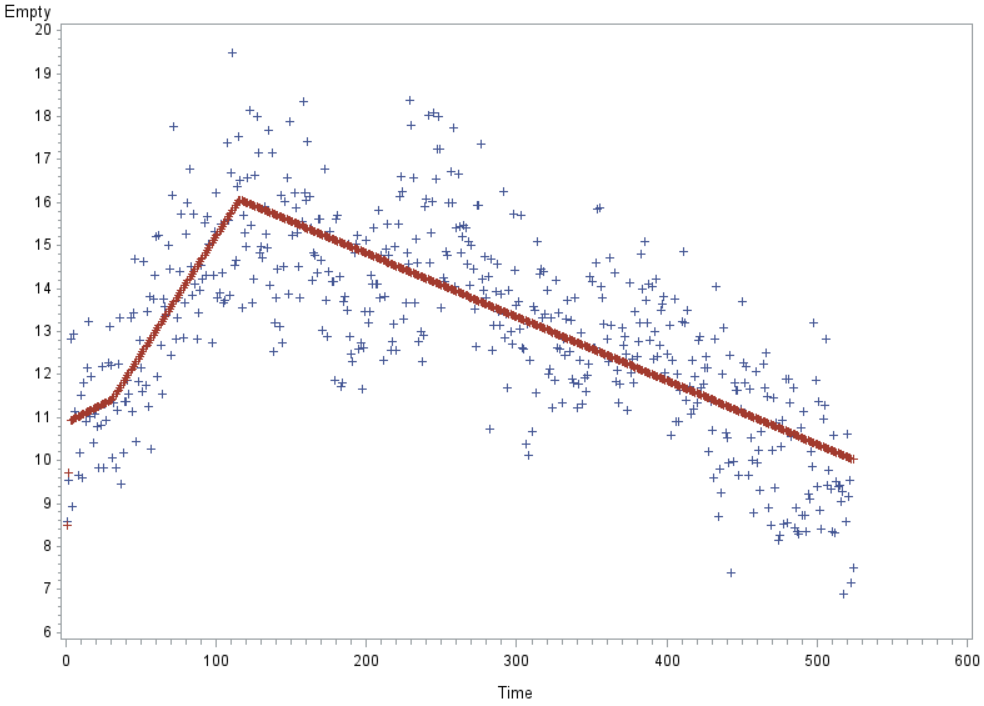

Figure 12. Plot & M-P regressions of average counts vs time for Empty sensor-- Group 1.

Group (2,3): The results of the multi-phase regressions of the average corrected Central sensor counts for Group (2,3) are displayed in Table 11 and Figure 13. As with Group 1's Central sensor data, a 3-segment, 2-change-points model is determined to be adequate and is fit using PROC NLIN in SAS. Initially, the sensor counts increase very quickly; at the first change-

point of 30 minutes, the sensor counts have increased to a peak estimate of 42 per 10 minutes. They then begin to drop rapidly, falling to a value of 24.5 at the second change-point of 178 minutes. From then on, the rate decreases slowly so that it is about 19 at the end of the observation period. Since the sensor counts reveal the activity of termites, the activity level of the termites was very high at the beginning of the experiment, which can be explained by many termites leaving the Central chamber and less activity thereafter. Overall, the change in activity level of termites at the Central sensor for Group (2, 3) is very similar to that of Group 1.

The results of the multi-phase regressions of the averaged corrected Food sensor counts for Group (2,3) are displayed in Table 12 and Figure 14. As with Group 1, a 4-segment, 3-change-point model is determined to be adequate for the Food sensor counts. Initially, the corrected sensor counts reach a peak of 22 counts/10 min at about 35 minutes. This first-change-point is close to the fist peak of the Central senor counts. Then, the Food sensor counts drop back to 16 counts/10 minutes at 140 minutes. To that point, the first two change-points of the Food sensor counts are very close to those of the Central sensor. However, after the second change-point, the average activity of termites around the Food sensor increases rapidly again to 35 counts/10 mins until 1140 minutes and then gradually increases to about 37 counts/10 mins, which is very different from the behavior of the Food sensor for Group1, as shown in Figure 11. For Group 1, the fourth segment (after CP3) has a negative slope, falling from 25 to 17, while for Group (2,3), the average corrected Food sensor activity level increases from 35 to 37 at the end of the period.

The results of the multi-phase regressions of the Empty chamber sensor count for Group (2,3) are shown in Table 13 and Figure 15. As was the case for Group 1, a 4-segment, 3-change-point model is fit for the Empty sensor. The first change-point for the Empty sensor is found to occur at 24 min. The early behavior of the Empty chamber sensor for Group (2,3) is somewhat

similar to that of the Empty chamber sensor of Group 1 shown in Figure 12. That is, we observe a first shift in slope of activity level at 24 minutes (where the activity level estimate is 10), with an increase to 20 at 475 minutes, and a long gradual climb to 34 at 3530 minutes, before falling to 29 at the end of the observation period. Compared to Group 1's Empty chamber sensor count, Group (2,3) takes much longer to reach its maximum (3530 minutes compared to 1150) and exceeds a count of 20 per10 minutes for over 90% of the observation period, whereas Group 1's Empty sensor count never exceeds 16 per 10 minutes at any point in the analysis.

In both Group 1 and Group (2,3), within a few hours, there is more activity at the Food sensor than there is at the other two sensors, but Group (2,3) has much a higher level than Group 1. The amount of activity at the Central sensor is about the same for the two groups and the pattern over time is similar. The major difference occurs with the Empty chamber sensor, where activity is low and decreasing over time for Group 1, but is higher than it is at the Central chamber sensor for Group (2,3). What this all means is not clear. As shown in Section 4.1, Group (2,3) has much more activity than Group 1, with this section demonstrating that the increase occurs at both the Food and Empty sensors, but not particularly at the Central sensor. Perhaps Group 1 colonies prefer to live where the Food is, so they don't venture out much once they reach that chamber, while Groups (2,3) prefer to live at the Empty chamber, transporting food as needed, leading to more activity near both sensors. Even if this were true, it provides little insight into the question of why a colony would become a Group 1 colony or a Group (2,3) colony. Separate multi-phase regression analyses of individual replicates do little to resolve this matter, as the data is very noisy. Replicates from the same group tend to have (count vs time) plots that are like those for the group average, although the locations of the change-points can vary a lot, as do the absolute values of the peaks. Indeed, one could argue that one should not be averaging

counts over replications that vary so much, but rather should be comparing relative levels of (C,F,E) counts within each replicate. This topic is investigated in Section 4.3

Table 11. M-P regression estimates for averaged counts for Central sensor -- Group 2,3

Parameter	Estimate	Approx Std Error	Approximate 95% Confidence Limits	
CP1	3.0138	0.3196	2.3859	3.6418
CP2	17.7645	1.1443	15.5164	20.0125
CP3	78.0000	45.9298	-12.2324	168.2
beta0	23.3235	3.3805	16.6823	29.9646
beta1	6.2767	1.5648	3.2024	9.3509
beta2	-1.1961	0.1467	-1.4844	-0.9079
beta3	-0.0227	0.0161	-0.0543	0.00890
beta4	-0.00970	0.000814	-0.0113	-0.00810

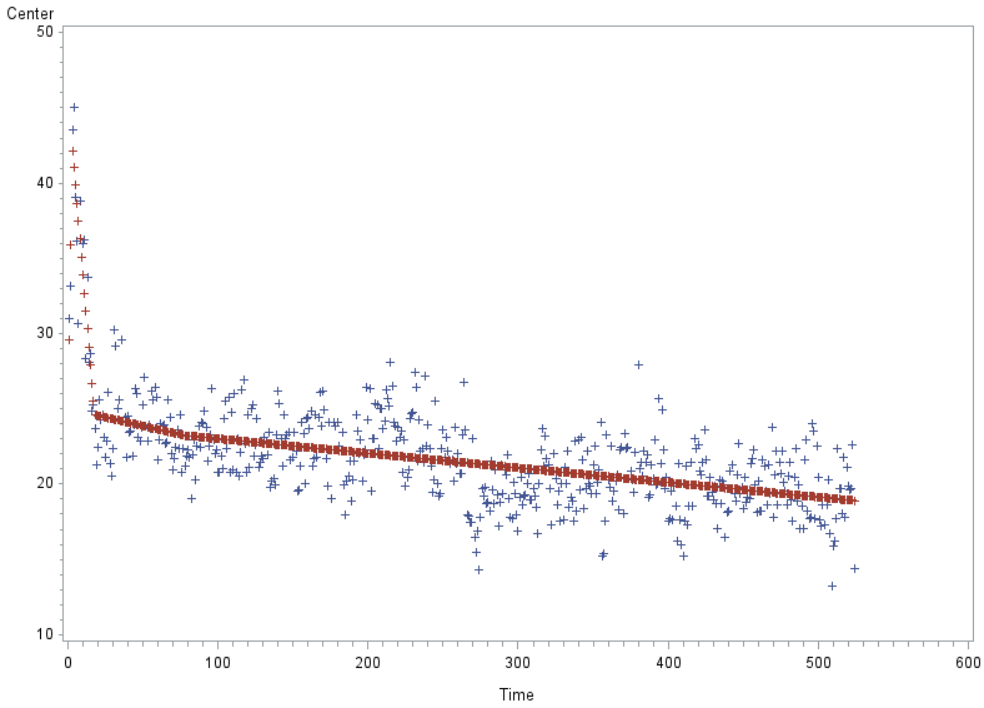

Figure 13. Plot & M-P regressions of average counts vs time for Central sensor- Group 2,3.

Table 12. M-P regression estimates for averaged counts for Food sensor -- Group 2,3

Parameter	Estimate	Approx Std Error	Approximate 95% Confidence Limits	
CP1	3.5422	0.5683	2.4257	4.6587
CP2	14.0000	6.9247	0.3960	27.6040
CP3	114.0	4.5568	105.0	123.0
beta0	-4.3611	4.6166	-13.4307	4.7085
beta1	7.1887	2.1371	2.9903	11.3872
beta2	-0.1110	0.2882	-0.6771	0.4552
beta3	0.1505	0.0105	0.1299	0.1710
beta4	0.00336	0.00126	0.000881	0.00584

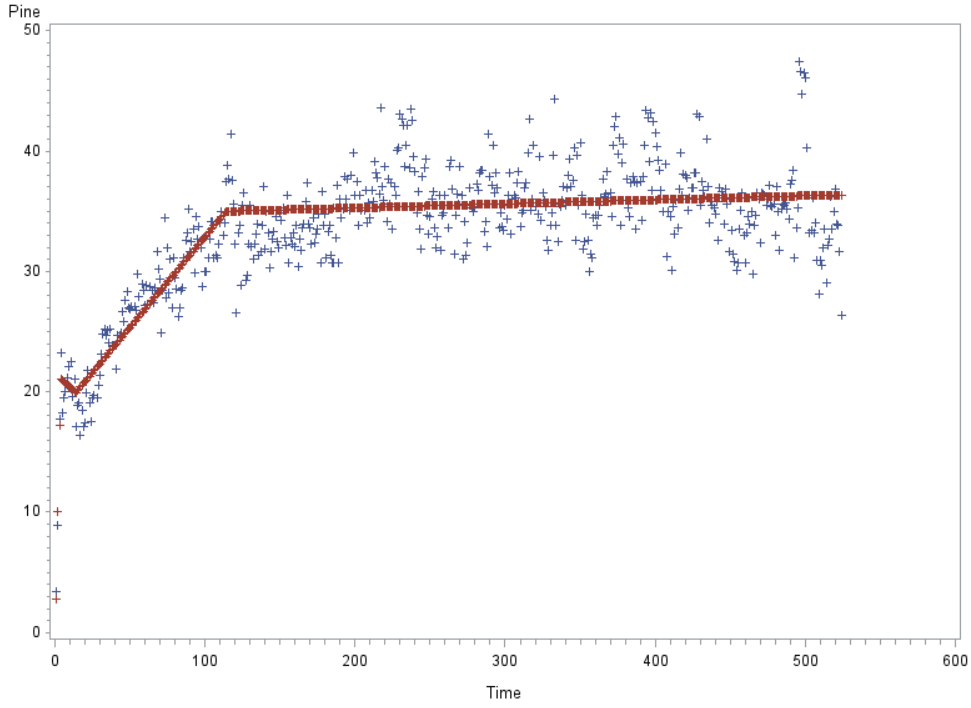

Figure 14. Plot & M-P regressions of average counts vs time for Food sensor -- Group 2,3.

Table 13. M-P regression estimates for averaged counts for Empty sensor -- Group 2,3

Parameter	Estimate	Approx Std Error	Approximate 95% Confidence Limits	
CP1	2.4285	1.4206	-0.3623	5.2193
CP2	47.4764	5.1730	37.3138	57.6391
CP3	353.0	6.6794	339.9	366.1
beta0	3.3875	5.7422	-7.8935	14.6685
beta1	2.9567	3.6317	-4.1780	10.0914
beta2	0.2070	0.0295	0.1491	0.2649
beta3	0.0485	0.00166	0.0453	0.0518
beta4	-0.0250	0.00398	-0.0328	-0.0172

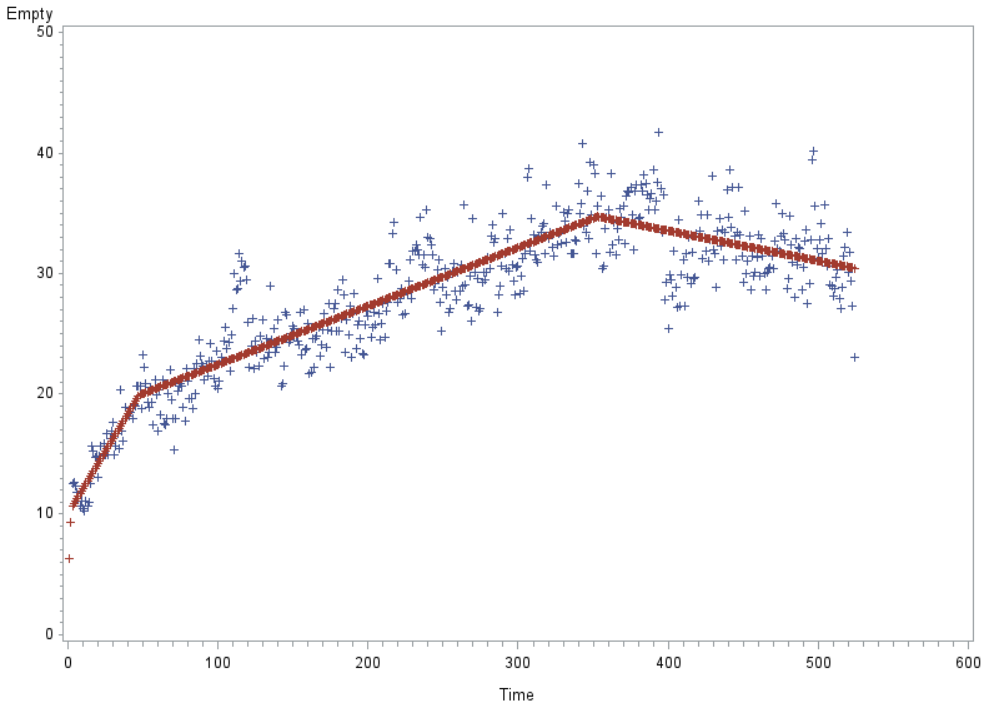

Figure 15. Plot & M-P regressions of average counts vs time for Empty sensor -- Group 2,3.

4.3. Analysis of Sensor Count Ratios

Since the absolute sensor count values differ so much between replicate experiments, even within the same group, we decided to see if performing analyses on relative measures would lead to more stability in estimates. The ratio (F/C) of corrected Food sensor counts to corrected Central sensor counts, (F/E) of corrected Food sensor counts to corrected Empty sensor counts, and (C/E) of corrected Central sensor counts to corrected Empty sensor counts, were calculated, respectively. This was done at the replicate level over the 524 10-minute blocks used previously. To avoid zeroes or infinite values in these ratios, 0.5 was added to both numerator and denominator counts before the ratios were calculated. As is typical with ratio estimates, a log-transformation was found to lead to more symmetry in distributions, so it was applied. The average over the replicates in a group of the ln(F/C), ln(F/E), and ln(C/E) were calculated at each time point, plotted, and analyzed as described below.

Figure 16 below illustrates ln(F/C) versus time for Group 1 and Group (2,3). From the plots, we can see that two curves are very similar, rising sharply from time zero to about 1000 minutes, at which point they level off at a value near 0.5. Figure 17 illustrates ln(F/E) versus time for Group 1 and Group (2,3). Both shoot up rapidly, surpassing zero within 30 minutes, but they level off at very different levels, about 1.1 for Group (2,3) and about 0.3 for Group 1. Figure 18 illustrates ln(C/E) versus time for Group 1 and Group (2,3). Both groups' plots fall rapidly as termites leave the Central chamber in the first hour, but Group 1 levels off at a slightly positive value, since the corrected Central sensor count tends to be greater than the corrected Empty sensor account for Group 1. For Group (2,3), this levels off at a negative value, since the corrected Empty sensor counts tend to be greater than the corrected Central sensor counts.

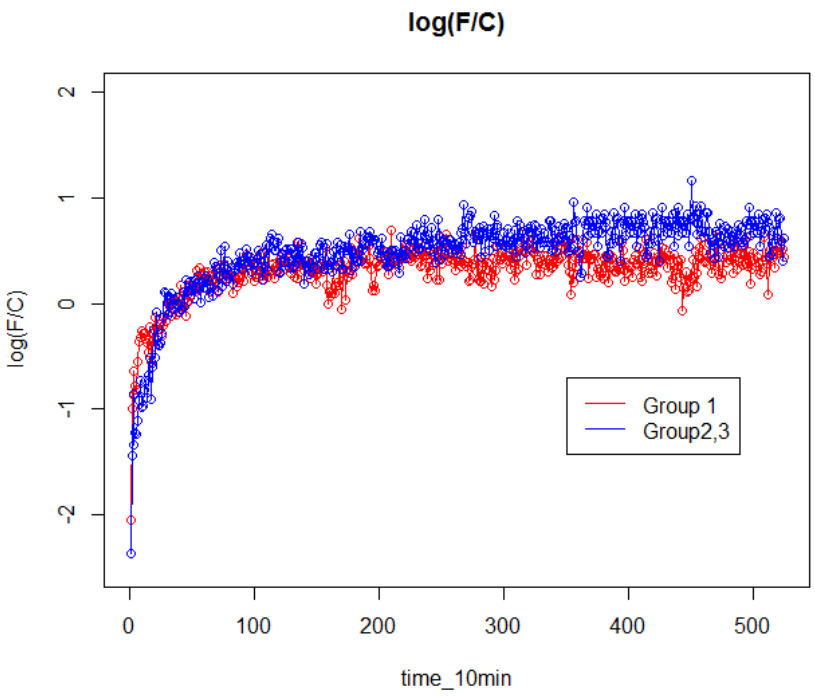

Figure 16. Plot of ln (F/C) versus time by group

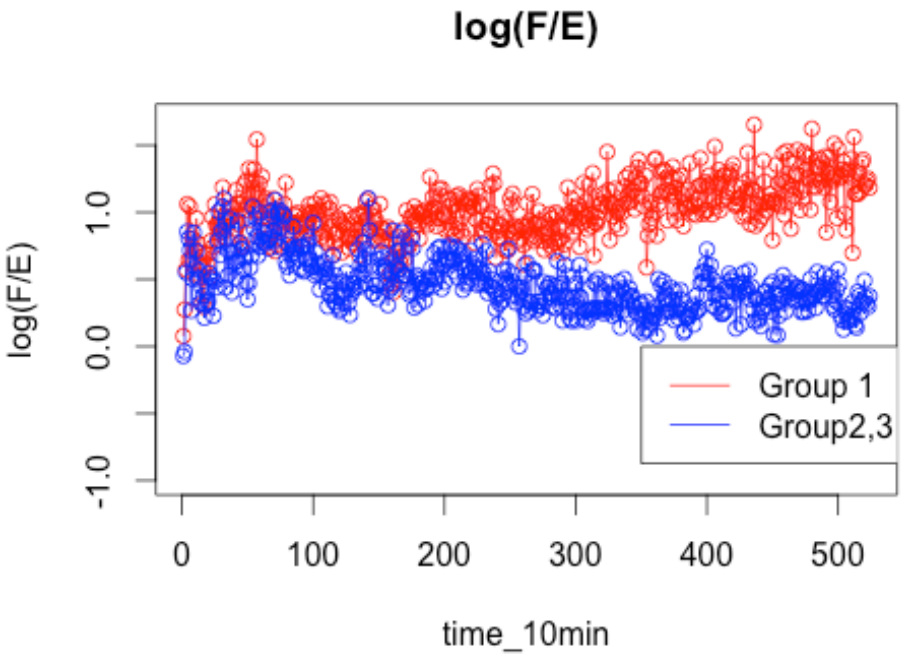

Figure 17. Plot of log(F/E) versus time by group

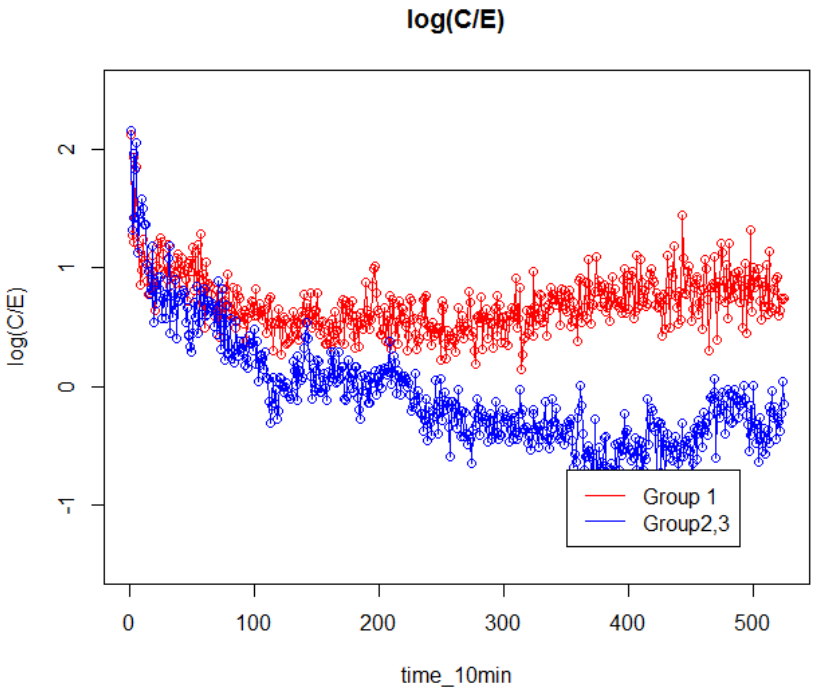

Figure 18. Plot of log(C/E) versus time by group

As in the Total analysis of Section 4.1, we are somewhat concerned with how typically the mean log-ratios plotted for each group in Figures 16, 17, and 18 represent the log-ratios of the replicates which form that group. So, as in Section 4.1, we'll summarize each replicate series by its 10 degrees-of-freedom smoothed spline. Then, similar to what was done in Section 4.1 for the Total Counts, we'll perform t-tests at each time point to see where statistically significant evidence exists that the two groups have diverged in mean.

Figures 19 and 20 show the smoothed splines and time-period specific t-tests, respectively, for the ln(F/C) series. Consistent with what is shown in Figure 16, the splines for the two groups show much overlap over the entire region, with both, very early in their series, reversing the preference for Central over Food before heading to a limit of approximately 0.5 (corresponding to an (F/C) ratio of about 1.65) after about 1000 minutes. Figure 16 would seem to imply that Group (2,3) has a statistically significantly larger mean ln(F/C) value than does Group 1, but the plot of Replicate smoothed splines in Figure 19 fails to show much separation, and the time-period specific t-test plots in Figure 20 show that while the typical t-statistic (Group 1 minus Group 2,3) is more likely to be negative than positive, the t-statistic doesn't fall below the 5% threshold (-1.7) much more than would be expected by chance. Thus, overall, the ln(F/C) statistic doesn't offer much help to differentiate the two groups.

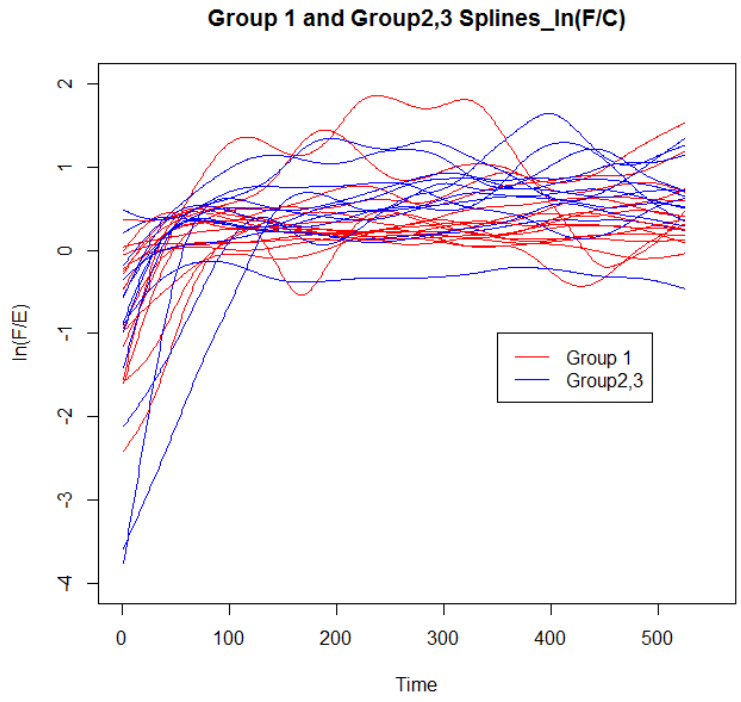

Figure 19. Plot of smoothed splines of ln(F/C) for 29 individual reps over time

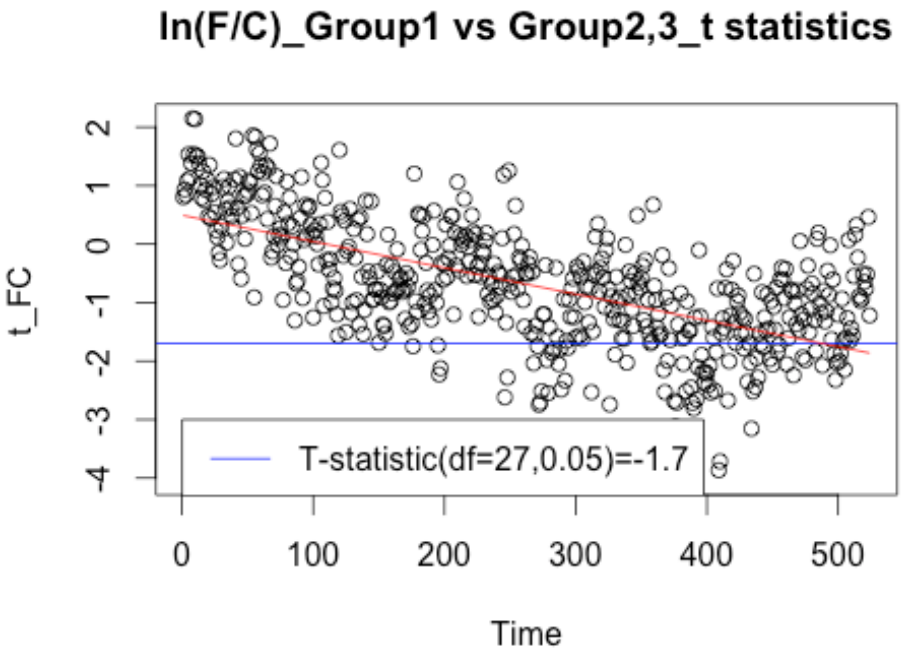

Figure 20. Plot of t-statistics of ln(F/C) of (G1-G2,3) over time

Figures 21 and 22 give the smoothed splines and time-period specific t-tests, respectively, for the ln(F/E) series. Consistent with what is shown in Figure 17, the splines for the two groups show much overlap over the beginning of the time period, but after a certain point, most of Group 1 (Red) follows splines consistently higher than those in Group (2,3) (Blue). There is one glaring exception, the Blue spline that is higher than almost all Red splines. This belongs to Replicate 36, one of the most bizarrely-behaved of all the replicate experiments. We considered simply deleting Replicate 36 from the analyses, but ultimately chose to leave it in, just to emphasize the fact that there is much randomness in these experiments. While both groups approach a positive limit (showing that both groups are more active near the Food chamber than near the Empty chamber), for Group 1, the log-ratio limit appears to be around 1.1 (corresponding to an (F/E) ratio of about 3.0), while for Group (2,3), the final log-limit is around 0.3, corresponding to an (F/E) ratio of about 1.35. Figure 17 would seem to imply that Group 1 has a statistically significantly larger mean ln(F/E) value than does Group (2,3), and the plot of replicate smoothed splines in Figure 21 does seem to confirm this except for Replicate 36. The time-period specific t-test plots in Figure 22 show that the typical t-statistic (Group 1 – Group 2,3) is more likely to be positive than negative after the first two hours, but the t-statistic doesn't consistently fall above the 5% threshold (+1.7) until about approximately 2700 minutes (45 hours). So, while it is true that the two groups behave statistically different with respect to ln(F/E) behavior, the statistical evidence needed to detect this difference doesn't manifest itself until about the mid-point of the time series. It would undoubtedly occur earlier if not for the presence of Rep 36, which, by itself, pulls the Group 2,3 mean up quite a bit. Thus, overall, the ln(F/E) statistic does eventually help to differentiate the two groups.

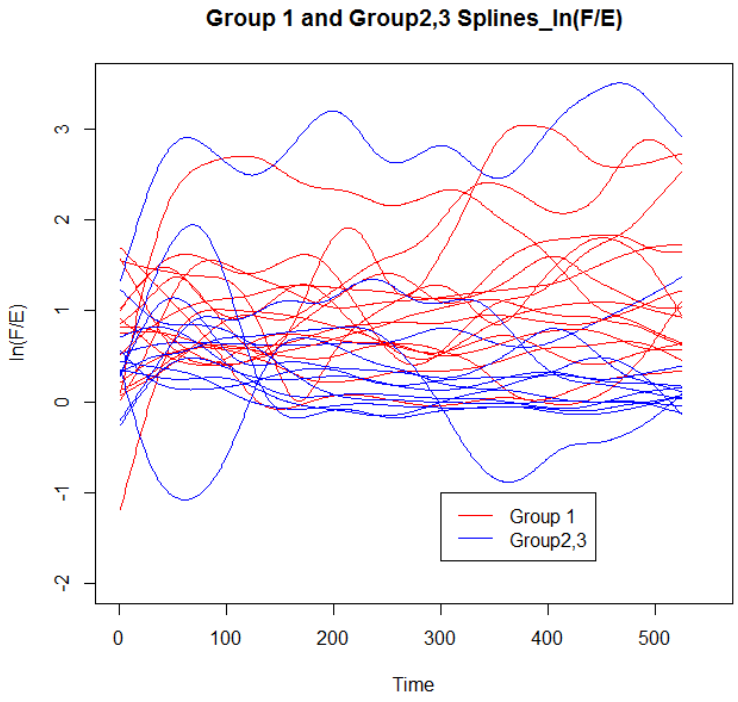

Figure 21. Plot of smoothed splines of ln(F/E) for 29 individual reps over time

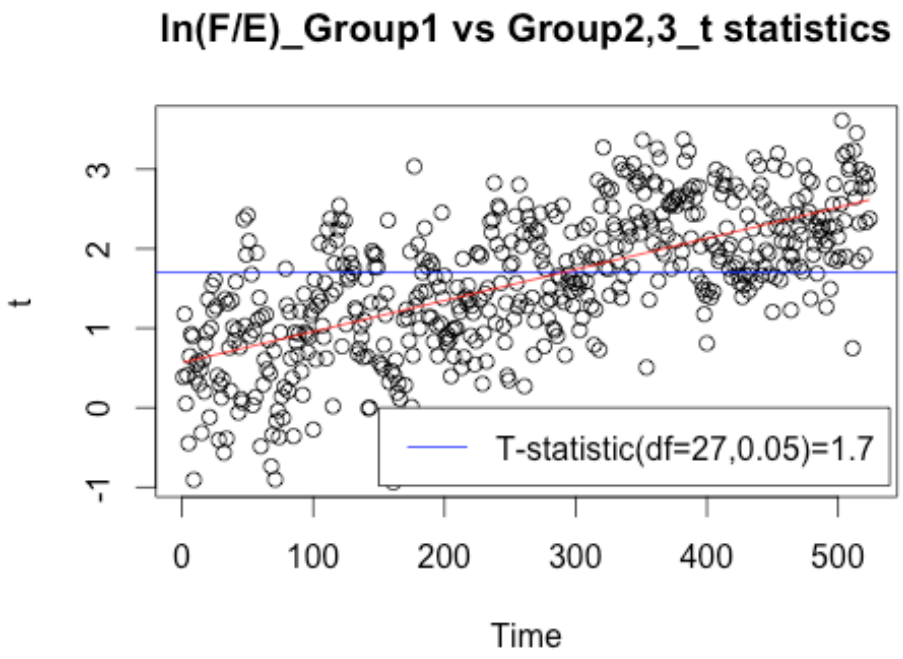

Figure 22. Plot of t-statistics of ln(F/E) of (G1-G2,3) over time

Figures 23 and 24 display the smoothed splines and time-period specific t-tests, respectively, for the ln(C/E) series. Consistent with what is shown in Figure 18, the splines for these two groups diverge rather markedly early in the observation period, with Group 1 approaching a positive limit and Group 2,3 approaching a negative limit, as the groups have almost completely opposite long-range propensities for activity near the Central and Empty chambers. Thus, most of Group 1 (Red) follows splines consistently higher than those in Group 2,3 (Blue). The time-period specific t-test plots in Figure 24 show that the typical t-statistic (Group 1 – Group 2,3) is positive after the first two hours, and the time-period specific t-statistics begins to consistently fall above the 5% threshold (+1.7) after about approximately 2700 minutes (45 hours). Of the three log-ratio statistics, ln(C/E) series best differentiates the two groups at an early time, and would do so even earlier if not for the presence of the outlying Replicate 36.

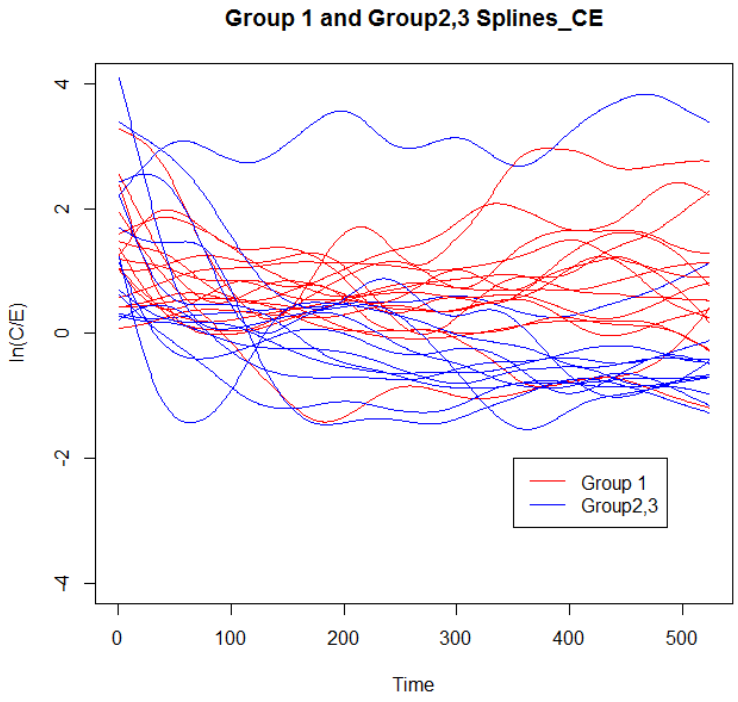

Figure 23. Plot of smoothed splines of ln(C/E) for 29 individual reps over time

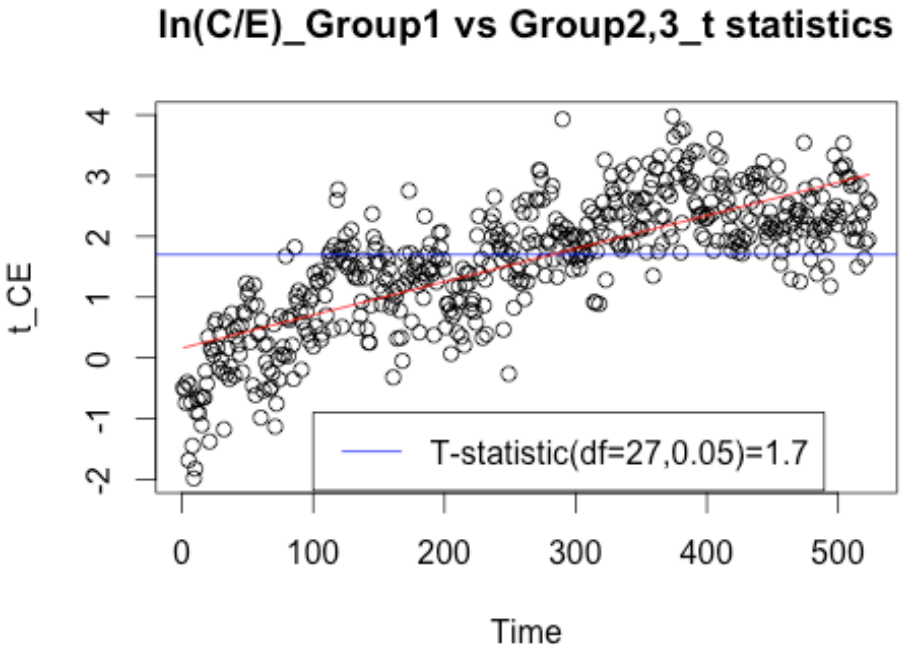

Figure 24. Plot of t-statistics of ln(C/E) of (G1-G2,3) over time

Figure 25 below offers some final summary on what has been found in this section of the thesis. What is displayed there are three splines fit to the differences (Group 1 – Group 2,3) between the mean log-ratios calculated previously. The Blue curve is for the ln(F/E) difference, while the Red and Green curves pertain to the mean ln(F/C) and ln(C/E) differences, respectively. These plots echo what was shown above. That is, both the red mean ln(F/C) and the green ln(CE) differences are consistently positive throughout the period of observation, and from about 2700 minutes onward, these differences are sufficiently positive enough to be significant. The Blue curve for differences in mean ln(F/E), however, never drifts far enough away from zero for significance to be declared (although from the time-period specific t-tests of Figure 20, it appears that there was a fleeting period of near significance around 4500 minutes).

In interpreting the splines of Figure 25, it should be remembered that these are second-order representations of the data. First, the 17 and 12 log-ratios for Group 1 and Group (2,3), respectively, must be averaged and their differences calculated. These values, which are summaries of 29 different replicates' log-ratios, are demonstrated for the ln(C/E) differences by the green circles in Figure 26. Even these averaged values are noisy, not admitting easily to fit by simple functional forms. The degree-5 splines used in Figures 25 and 26 are compromise smooth functions that display the general behavior of the difference in means, but certainly don't yield i.i.d. normally distributed residuals. For Figure 26, the residual SD of 0.228 appears to relatively constant throughout the observation period. However, the many clusters of positive and negative residuals indicate statistical dependence, and a very significant first-order autocorrelation of $\rho=+0.285$ is measured. Further quantification of the dependence in successive measurements is not attempted here; it would be more appropriate applied to series at the Replicate level.

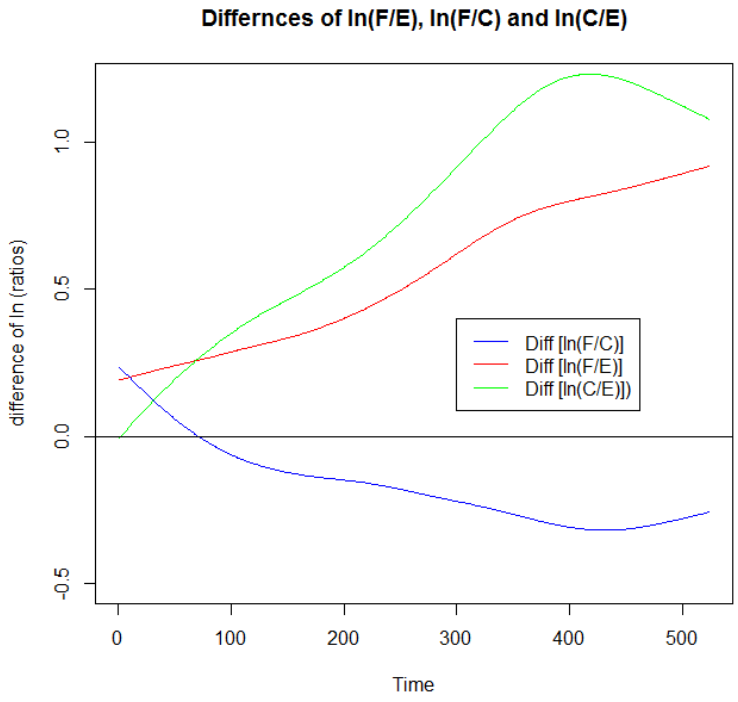

Figure 25. Smoothed splines of differences of ln(F/C), ln(F/E) and ln(C/E) between Group 1 and Group 2,3

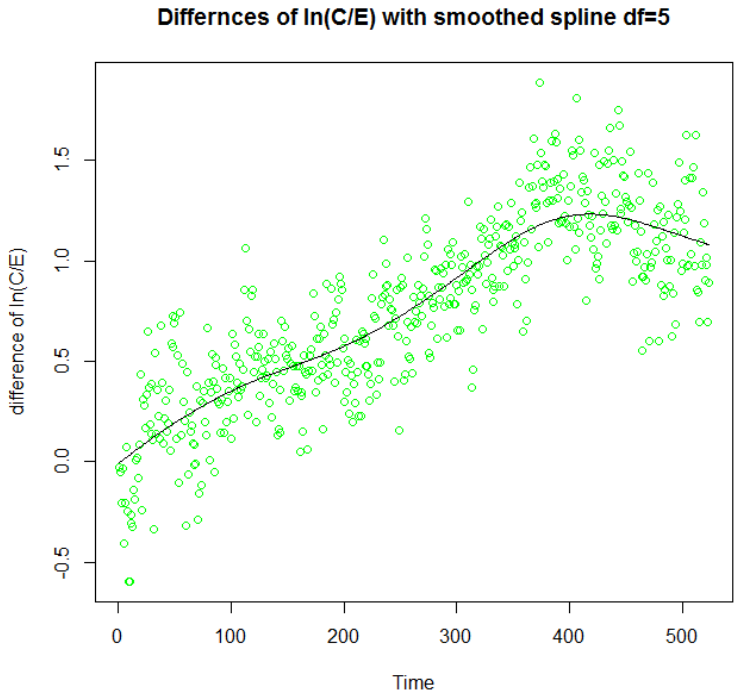

Figure 26. Plot & spline of difference in ln(C/E) between Group 1 and Group 2,3

5. Conclusions

The 36 replicates can be divided into three groups based on their final settlement into Central, Food, and Empty chambers. Sensor count data were analyzed separately for two groups (Group 1 and Group 2,3). From the analysis of sensor count data from Group 1, we find that the activity of termites at the Food sensor was the highest, whereas the lowest activity occurred at the Central chamber sensor. The activity level of termites declines after a certain time at both the Central and Empty sensors, but with Central always greater than Empty. The mean activity level at the Food sensor for Group 1 increased until about 590 minutes (10 hours). After that point, the mean activity level decreased monotonically, but was always greater than the activity level for the Central chamber which, in turn, was always greater than that of the Empty chamber's sensor. From the analysis of sensor count data for Group (2,3), the average activity of termites was the highest at the Food sensor, whereas the lowest average activity was observed at the Central sensor. The average activity of termites declines after a certain time point at the Central sensor, but continues to increase at both Food and Empty chamber. For both groups, termites seem to find the food very quickly, but the movements of termites after finding the food are significantly different between the two groups.

Within a group, there was much variability between replicates, and some replicates' (notably Replicate 36) termites seemed to behave more like termites from the other group, while a few replicates (notably Replicate 13 and Replicate 17), at times, were much different from any other replicate. Similarly, no statistically generalizable conclusions could be made regarding the process by which different termites chose to enter the Y-tube; there was no clear division between termites with respect to propensity to enter the Y-tube. Despite these shortcomings, we feel that the general conclusions of Section 4.3 concerning termite long-range behavior are valid.

6. References

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7. Appendix

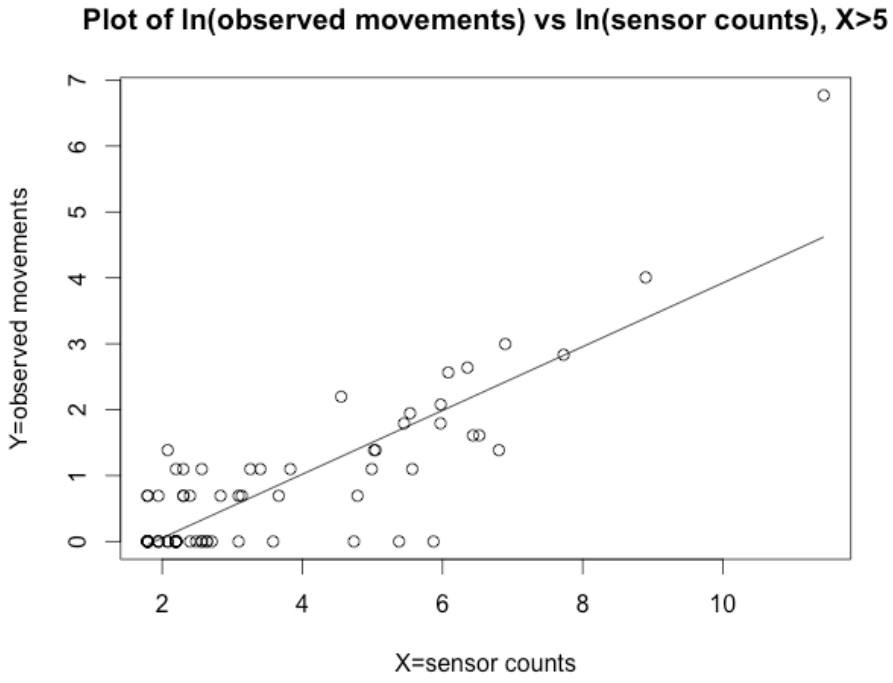

Figure A1. Plot of ln (observed movements) vs ln (sensor counts) and fitted line for sensor counts greater than 5