Beware of Elephants: Discovering the Most Effective Repellents to Ward off Unwanted Elephants

Alayna Daws, Student 2, Student 3
With Dr. Marguerite Madden of the University of Georgia Geography Department
Capstone II

1. Introduction

The region of Southern Africa is facing an issue concerning the safety of humans and elephants. In this area, elephants can often be found in popular tourist areas and on local farmers' lands. This poses a risk to both humans and elephants. The elephants are destroying valuable crops, damaging property, and putting people at risk just by being in close proximity. Elephants are also at great risk of harm because farmers will often shoot them if they enter their land, they have access to harmful garbage in dumpsters, as well as many other threats posed just by being around humans. The main culprits are bull elephants which are adult male elephants. Elephants are matriarchal, so when the bulls are old enough they will leave the family and join other "bachelor" elephants. Bull elephants are the largest and most aggressive of the species, so they pose the biggest threat to human safety. Because there are so many threats to elephant and human safety, there is speculation over the best ways to repel these elephants from dangerous areas. While bull elephants tend to be the most violent towards humans and their occupied areas, most of the following experimentation will likely be run on female elephants, since they are more friendly and cooperative to humans and are more likely to be human-influenced.

One method that has found some success is filling ping pong balls with chili oil and launching them at elephants that trespass onto farmland. This has shown to be effective in getting rid of the elephant without causing them harm. However, this is a method that is used only once an elephant has entered an area it should not have. A better solution would be to prevent the elephant from ever entering the land. Another ongoing study is using drones to repel elephants. Elephants are scared of bees, so the drones mimic the buzz of a bee to scare the bulls off.

This knowledge can be used to develop an experiment to determine the best repellents to keep elephants out of dangerous areas. Throughout the rest of this paper, an experiment will be outlined that will test various possible repellents in order to determine the most effective deterrent. The data that will be collected will be discussed as well as the creation of simulated data to use as a stand-in until real data can be collected. The proposed analysis will also be described and conducted on the simulated data.

2. Experiment

Through the Victoria Falls Wildlife Trust and Conservation Connect, experimentation can be run on two to three bull elephants in an enclosure that spans over one hundred miles. This enclosure mimics the wild that the bull elephants were used to, but allows for conservationists to keep close tabs on them and conduct experimentation. Since the goal of this experiment is to keep young bull elephants away from crops in order to keep them from being shot and killed or injured by farmers, this setup will try to imitate what the elephants would encounter in real life.

The experimentation deployed for this research will focus on applying different treatments to a fence blocking off substances of interest to the bull elephants. The substances inside the fence should be enticing enough to draw the elephants to the site of the experiment. This fence is made to mimic the type of fence that would be used to block off crops from the elephants and other wildlife. The fence will then be treated with different strategies to keep the elephants away from the fruits or other substances of interest to the elephants. The treatments that will be tested are chili-oil, shiny objects, bee simulation, and the control, a standard fence. The first treatment applied will be the chili oil to the fence. Like the previous research, if the elephants get close enough to the fence and the chili oil goes inside their nose and mouth, they will be deterred and not want to get close to the fence again. The second treatment will be applying shiny objects, such as aluminum foil, to the fence. Previous research has also suggested that elephants do not approach things that reflect light. Next, there will be a bee-like simulation set up on and around the fence. This will be achieved through speakers to mimic bees buzzing. Elephants do not favor bees as they are sensitive to their stings in their large ears, so they tend to stay away from bees if they believe they are nearby. The control in this experiment will mimic the same set-up for the other treatments with a fence, but no treatment will be applied to the fence.

Throughout the experimentation period, there will be a camera set up that has a full view of the fence and the contents it surrounds. It will also be able to see the elephants as they approach the fruit enclosure. There will likely be more than one camera to ensure accuracy from each angle. The camera(s) will produce film that is time-stamped so that the data can be coded to time. This will ensure that the variables will all be collected properly and accurately.

3. Data

The data collected from this experiment will take the form of ranked data and measurements of time. Data were simulated to best represent expected experimental results using previous research and guidance from Dr. Marguerite Madden, the Director of the Center for Geospatial Research in the University of Georgia Department of Geography. Data were simulated due to a lack of time to both design and execute the experiment. Simulation has allowed the experimental design to be tested and adjusted accordingly. The sample size of the simulated data is two. It is expected two elephants will be available as the test subjects when the initial experiment is conducted. Only two elephants are available for experimentation due to limited resources: time, money, and materials. It should be noted that the power of the study is reduced and the margin of error is increased when the sample size is small. This will be taken into account when interpreting results. Long term, the goal is to conduct the experiment with more elephants as the initial experiment is proof of concept. The data itself will be collected from the video received from the camera(s) at the enclosure. The types of data that will be obtained from the experiment site are summed up in Table 1.

Table 1: Variable Descriptions.

	Behavior	Vocalization	Time to Approach	Breakthrough
Approach 1	1 to 5	1 to 5	X seconds	0 or 1
Approach 2	1 to 5	1 to 5	X seconds	0 or 1
Approach 3	1 to 5	1 to 5	X seconds	0 or 1

Each row is designated for a different approach to the simulated crop enclosure. The amount of rows in the table represents how many approaches to the simulated crop enclosure the elephant makes before it breaks through. With each approach, four metrics will be obtained to use for analysis.

The “Behavior” metric, which is rated on a scale from one to five, is a scaled measure of the actions of the elephant leading up to the simulated crop enclosure. On this scale, one is calm and non-violent, while five is explosive and violent, keeping three at a neutral behavior level. This will be calculated by watching the video clip from each approach and using elephant behavior experts’ advice on how to score the behavior. Similarly, the “Vocalization" metric will be rated on a one to five scale and is the scaled measure of elephant vocalizations. On this scale, one would be little to no vocalizations, three would be some, and five would be loud continuous vocalizations. These are both highly important measures in helping researchers to quantify elephant behavior with regard to keeping them away from crop enclosures. The “Time to Approach" data will be taken in seconds to see how long it takes for the elephant to come into view of the camera and until the time it first makes contact with the simulated enclosure. This is an important metric because it can give insight into how hesitant the animal might be to approach the setup. Finally, “Breakthrough” data will be scored either a zero or a one. Here, a score of 0 will denote that the elephant did not break through the treated fence and a 1 will denote that the elephant did breakthrough. This data will then be cleaned and organized to be uploaded into an analysis tool.

In order to simulate the data, the expected real-world circumstances were taken into account. It is likely that two elephants will be used as that is how many are available at the elephant conservation with three attempts for each elephant with each treatment. First, the breakthrough variable was simulated. Table 2 shows the probabilities of breakthroughs for each treatment. If the elephant breakthrough on the first attempt, then the probability of a breakthrough on the following attempts was increased to 0.9. Research conducted by Karidozo and Osborn (2015) showed that it is unlikely that elephants would become immune to chili oil, so for the purposes of the simulation, if the elephant did not break through the first time, the probability of breakthrough stayed 0.1 for the subsequent attempts. Cook et al. (2018) found a similar lack of subsequent breakthroughs with beehives, so the same tactic was applied to the bee treatment simulation. This assumption was then carried over into the shiny object treatment as well.

Table 2: Simulated Breakthrough Probabilities.

Treatments	**Probability of Breakthrough**
Chili oil	0.1
Shiny Objects	0.3
Bee Simulation	0.1
Control	0.9

For the vocalization and behavior variables, these values were randomly selected from 0 to 5 based on equal probability. Once all of these observations were simulated, a full data set was compiled as can be seen in Table 3. The columns of the table are the different variables for both elephants with BT denoting breakthrough, BH denoting behavior, V denoting vocalization, and T denoting time to approach. The rows are the different treatments and attempts with C denoting chili oil, S denoting shiny objects, Bee denoting the bee simulation, and Co denoting control.

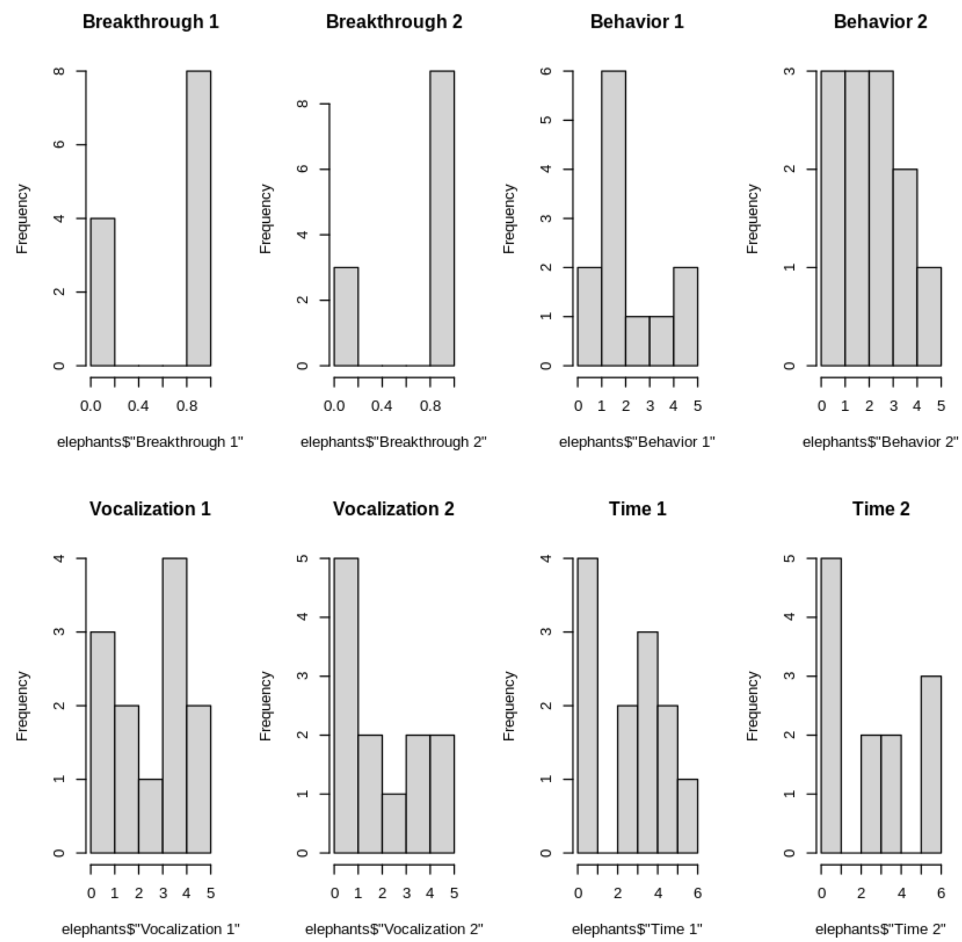
Table 3: Simulated Data

	BT1	**BT2**	**BH1**	**BH2**	**V1**	**V2**	**T1**	**T2**
C1	0	0	3	3	2	4	3.0777	2.1594
C2	1	0	2	0	2	1	3.7219	3.6445
C3	1	0	0	4	4	0	5.7163	0.9791
S1	1	1	1	4	4	5	0.8744	0.1255
S2	1	1	2	2	1	2	2.5329	3.0727
S3	1	1	4	2	5	3	2.2753	2.9649
Bee1	0	1	2	5	0	0	3.0134	5.8914
Bee2	0	1	5	0	0	2	4.4243	5.9247
Bee3	0	1	5	1	5	5	4.5216	5.7425
Co1	1	1	2	3	4	4	0.0469	0.3992
Co2	1	1	2	3	4	1	0.0162	0.9050
Co3	1	1	2	2	3	0	0.3919	0.2876

4. Exploratory Data Analysis

Although the data were simulated, it is helpful to run some preliminary exploratory data analysis on the data before an in-depth analysis is run.

Figure 1: Histograms for each variable by elephant



Just from these exploratory histograms, one can tell that the breakthrough variables have a tendency towards 1, which denotes the elephant broke through despite the treatment on the fence more often than not. This is consistent with the efficacy of the treatments that were tested. Looking at the histograms for the breakthrough variables, there are some discrepancies, which likely arise from the randomly simulated data. The histogram shows a much more even distribution for the second elephant. While this is simulated, it is possible that depending on the elephant being tested, the data could behave this way. Furthermore, the data for the vocalization variable is substantially different for each elephant as seen in the histogram, and the same holds true for the time variable. As mentioned, this could simply be a random simulation, or could hold true when tested on real elephants due to differences in personalities and other factors affecting the measurements of these variables.

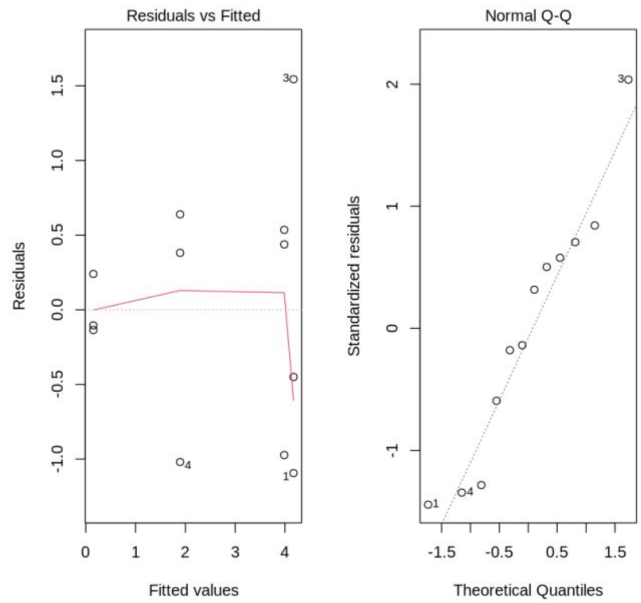
5. Data Analysis

In order to analyze the effectiveness of each treatment level in the experiment, two different types of models were used. The variable time to approach is continuous, so the model that will be used will be a one-way ANOVA. The other variables: behavior, breakthrough, and vocalization will be modeled using a Kruskal-Wallis by ranks one-way ANOVA. The variables will be looked at separately and considered independent.

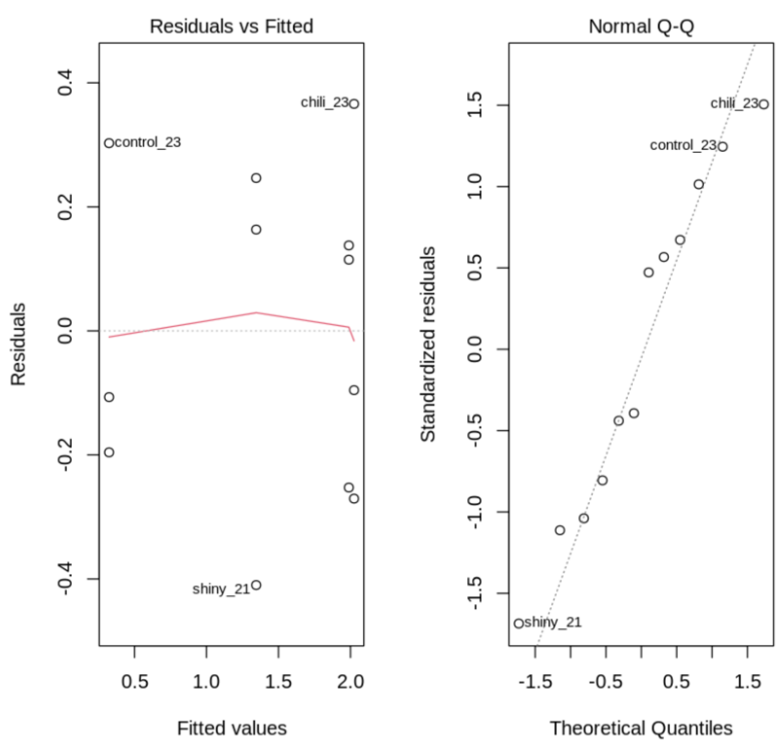
Prior to any analysis being conducted, it was important to average the time it took the elephants to break through. This was done to streamline analysis, create a larger, more robust dataset, and take out any variation based on elephant personality. This same process was not completed for the ranked variables because that would impede on their ranked nature, as ranked values are more easily swayed by averaging. Before any further analysis was done, the residual plots for the time variable were checked.

Figure 2: Residual vs. Fitted and Normal Q-Q Plot for Time Variable

Without a large amount of data, checking the assumptions of normally distributed residuals and residuals with constant variance can be difficult. Figure 2 shows the residual plots for the dataset with respect to the time variable. There seems to be somewhat of a fanning pattern in the Residuals vs. Fitted plot, which suggests that the residuals may not have a constant variance.



However, with so few points, it is difficult to make this assumption outright. Regardless, a Box-Cox transformation was performed to attempt to standardize the residuals.
Figure 3: Corrected Residual vs. Fitted and Normal Q-Q Plot for Time Variable



These plots show a much better Residuals vs. Fitted plot that reduces fanning and other patterns. Additionally, the Normal Q-Q plot shows residuals that follow the normal line better, suggesting the transformed residuals are more normally distributed. While it is still difficult to understand the full effect that the small dataset has on the analysis, it is important to recognize that this transformation makes a difference in checking the assumptions.

The model that would be used to determine the effect of each treatment is defined as

$$y_{ij} = \mu + \tau_i + \varepsilon_{ij}, i = 1, \ldots, k, j = 1, \ldots, n_i$$

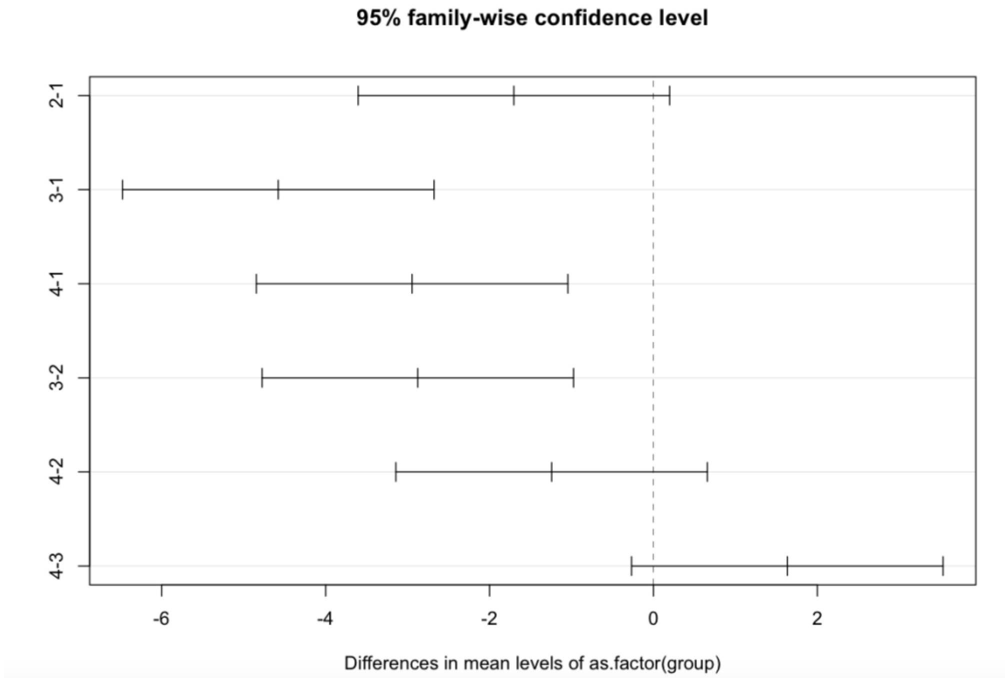
where y_{ij} is the j^{th} attempt with treatment level i out of a k number of levels, μ is the general average effect, τ_i is the effect of the i^{th} treatment level, ε_{ij} is the error, and n_i is the number of attempts. An F-test was conducted on this model in order to test the null hypothesis that each treatment effect is equal. The alternative hypothesis is that at least one treatment is effective. The F-statistic found from the one-way ANOVA for the first elephant conducted is 12.36, which corresponds to a p-value of 0.002109, which is less than the reasonable alpha level of 0.05. For the second elephant, the F-statistic is 13.00, and the corresponding p-value is .001922. Both these ANOVAs suggest that one should reject the null hypothesis, meaning that at least one treatment, either chili oil, shiny objects, or bee noises, is effective in delaying the time it takes for the elephants to approach the enclosure.

Given that the null hypothesis is rejected, multiple comparisons are completed to determine which treatment levels differ significantly.

Table 4: Tukey Test for Time to Approach - 95% Confidence

	Difference	**Lower**	**Upper**	**p-adjusted**
Chili - Bees	-0.4277	-1.1878	0.3324	0.3388
Control - Bees	-1.6388	-2.3989	-0.8787	0.0006
Shiny - Bees	-0.8834	-1.6435	-0.1234	0.0243
Control - Chili	-1.2111	-1.9712	-0.4509	0.0041
Shiny - Chili	-0.4557	-1.2158	0.3044	0.2925
Shiny - Control	0.7554	-0.0047	1.5154	0.0514

Figure 4: Tukey Plot for Time to Approach - 95% Confidence



Conclusions can be made regarding significant differences between treatments. It should be noted that the numbers 1, 2, 3, and 4 represent bee noise simulation, chili oil, control, and shiny object treatments respectively. Based on the output from the Tukey test at the 95% confidence level: control vs bee noise simulation, shiny object vs bee noise simulation, and control vs chili oil are significantly different. However, zero is a reasonable value for bee noise simulation vs chili oil, shiny object vs chili oil, and shiny object vs control so they are not significantly different. The p-value for bee noise simulation vs chili oil, shiny object vs chili oil, and shiny object vs control differences suggests that the two do not have a significant difference. The difference between the control and the bees is significant, citing a p-value of less than an alpha of 0.05. Chili oil and bee simulation are effective methods for keeping elephants away from crops.

The other variables, behavior, breakthrough, and vocalization, are rated on a one to five scale. This is the scaled measure of elephant vocalizations, so a non-parametric method was used. For these variables, a Kruskal-Wallis by rank one-way ANOVA was run to determine the significance of each treatment on the scale, non-continuous variables.

The assumptions for the Kruskal-Wallis test differ from that of the traditional one-way ANOVA. While there are residual components that need to be checked for the one-way ANOVA, these assumptions are not required for the Kruskal Wallis ANOVA. The assumptions for this test focus more on the variable type and distribution of the variable. For example, one of the assumptions is that the dependent variable is ordinal or ranked, which breakthrough, behavior, and vocalization are, as explained in the “data” section. The independent variable must be categorical and independent, which they are since we are relying on four separate treatments.

A third assumption states that observations must be independent of one another. Since the elephants should not be approaching more than one treatment at a time, this assumption is checked. Finally, each group's distribution should have the same shape. Since all four treatment variables were simulated from the uniform distribution, this assumption would also be checked. If real data were to be examined, one would need to provide histograms of the variable distributions to check this assumption.

The null and alternative hypotheses are the same as in the one-way ANOVA. The test statistic that was calculated for each variable is

$$H = (N - 1)(\Sigma^g{}_{i=1} n_i(r^-{}_i - r^-)^2 / (\Sigma^g{}_{i=1} \Sigma^g{}_{j=1} n_i(r_{ij} - r^-)^2,$$

Where N is the total number of observations, n_i is the number of observations in group i, g is the number of groups, r_{ij} is the rank of observation j from group i, $r^-{}_i$ is the average rank of all observations in group i, and r^- is the average of all the r_{ij}. After calculating H, it will be compared to H_c which is the critical value obtained based of the chosen significance level, α.

Table 5: Kruskal-Wallis Rank Sum Test Results

Variable	**Chi-Squared**	**p-value**
Breakthrough 1	8.25	0.04112
Breakthrough 2	11	0.01173
Behavior 1	3.2267	0.358
Behavior 2	0.33213	0.9539
Vocalizations 1	1.4371	0.6969
Vocalizations 2	1.7674	0.6221

To complete the Kruskal-Wallis Rank Sum Test, it is assumed that the distribution is identically shaped and scaled across all groups. The groups in the simulated data are represented by the treatments: chili oil, shiny objects, simulated bee sound, and the control. The null hypothesis is that medians across the groups are equal. The alternative hypothesis is that at least one median population for a group is different from the population median of at least one other group. The Kruskal-Wallis Rank Sum Test was applied to each of the variables for each approach. Each p-value test result is compared to the set alpha level of .05. The null hypothesis stating the medians across the groups are equal is rejected for both breakthrough approaches. It can be interpreted that the median breakthrough rank of at least one group is not equal. This is true for both approach 1 and approach 2. However, the population medians across all of the groups for behavior and vocalization variable rankings across both approaches are not considered different due to a p-value greater than alpha.

6. Caveats

Despite the positive results of the analysis, there are some shortcomings that come along with this experiment and therefore with its results. The first is due to the fact that the data being analyzed was simulated and not collected through a physical experiment. This leads to the probabilities, while based on research, possibly not being the true probabilities of each event occurring. Real-world data may be vastly different or very similar to the simulated data, however, the simulated data is a useful tool in setting up the analysis that will then be replicated on the real data when it is collected.

The shortcomings of the availability of elephants to use as observational units should also be addressed. There are currently only two elephants that can be used for this experiment, and they both happen to be female elephants rather than bull elephants. Ideally, there would be many elephants that could be used with multiple attempts, but in reality, that is not a possibility at this time. The fact that the two elephants available are females is also not an ideal situation considering the target of the experimentation is focused on safety centered around bull elephants. However, analyzing the data collected even from elephants of different sex could still be useful in predicting how each treatment will deter bull elephants.

Due to the small sample size, the residuals for the time variable may be misleading. Fanning was observed in Figure 1 Residuals vs Fitted plot, which could be cause for concern, but with such a small sample size and the use of simulated data, the pattern may change with more data points or when using data collected from physical experimentation. Figure 1 Normal Q-Q plot showed that the residuals are approximately normally distributed which is promising, but it is still tenuous considering the size and source of the data.

7. Conclusion

While this experimentation will focus on how elephants react to the treatments upon the first encounter, it is also important to address the possibility that the elephants could become immune or accustomed to the treatments. In this case, it is worth referencing previous research on chili oil and bees and their effects on elephants. The research conducted by Karidozo and Osborn (2015) on chili fence and briquette deterrence for crop fields suggests that the elephants did not become accustomed to this treatment, that they were continuously deterred by the scent of the chili oil surrounding the crop fields. On the fields that had these fences up, no plots were destroyed, in any area, compared to the hundreds without the chili fences that were destroyed. Additionally, research by Cook et al. (2018) suggests significantly fewer secondary branch breakthrough when beehives were used to deter elephants from trees. While the proposed experimentation focuses solely on the noise imitated by a speaker, this research submits that even if elephants became immune to the treatment, it would take an increasingly long time for that to occur. Keeping these two pieces of literature in mind, it is important to note that as of now, there is no credible research to suggest that there will not be immunity to reflective objects. In any case, such immunity to treatments should be considered a further topic of research.

It is very important to the safety of elephants and humans that effective deterrents are found to keep elephants away from unsafe areas. In order to do so, an experiment must be conducted to find the repellant with the highest rate of success. The treatments that are suggested to be tested in real life are chili-oil, shiny objects, bee simulation, and control, a standard fence. Quantifying elephant reactions, vocalizations, time investigating or breaking through, and whether or not the elephant gets past the repellant are the variables that will be used to analyze the different treatments. These variables will be examined to determine which repellant kept the elephants away from the crop the longest and how hesitant they were around the repellant. At the end of this analysis, a conclusion will be drawn about which method appears to be most successful in preventing elephant trespassing.

In the future, we would like to see the experiment be conducted so analysis can be done on real data as opposed to simulated data. It would also be ideal for the experiment to be conducted on more elephants than the two previously proposed. The Victoria Falls Wildlife Trust has nine elephants currently within their conservation zone, and the experiment would be improved if all nine could be used as experimental units. Finally, once there is physical data, a power analysis should be run to test the strength of the model and determine whether there is a treatment that is statistically significant.

8. References

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