Team 3422 Summary: The native elk population in eastern North America went extinct more than one hundred years ago. In an attempt to restore the elk population, in 2001, a small population of the Manitoba Elk species, native to western regions of North America, was introduced in Great Smoky National Park (GSMNP). In this study, we looked at the potential for continued growth in that region. Our results indicate with confidence that the elk will continue to flourish in the future. Our mathematical model of the population provides a solid foundation for an elk growth and improvement plan, as it incorporates a realistic modeling of pertinent factors such as predation, disease, and abiotic variables. Elk predation was calculated by combining the Lotka-Volterra and logistic growth models between the two populations. Disease was examined by conducting a multiple regression analysis with relevant environmental conditions, including water quality, air quality, and climate in the region. We found a statistically significant correlation ($p = 0.0027$) between the linear relationship of sickness in the elk population and the combined effects of sulfate concentration in streams and ammonium concentration in precipitation. By extrapolating environmental trends over the past decade, the Manitoba Elk population is predicted to reach a stable value around 322 by the year 2060. We formulated an elk growth and improvement plan that focuses on increasing the potential for elk growth by emphasizing the importance of two main factors: predator populations and mineral concentration in water sources around GSMNP. We advocate using a response plan to bring extreme values of these two to normal levels through a combination of hunting, relocation, and sterilization for the black bears; and introducing natural and chemical agents into water sources to neutralize excess mineral concentrations. These measures will be able to preserve the elk population for years to come.

HiMCM 2012 Problem A

Team 3422 · November 11, 2012

1 Problem Introduction

The elk population native to the Eastern US, and more specifically the Great Smoky Mountain National Park (GSMNP), *Cervus canadensis canadiensis*, went extinct in the early 1800s due to habitat loss, overharvesting, and hunting. However, recent efforts have been made to restore some elk population back into the area through the introduction of the Manitoba Elk, *Cervus canadensis manitobensis*. While the two species are similar, the Manitoba Elk is smaller and more adapted to living in the environment of the western United States and Canadian prairie. The Manitoba Elk population has been observed over a period of 11 years in the GSMNP, especially monitoring births and deaths by poaching, sickness, accident, predators, and unknown reasons each year. The two-part problem is, given the data collected during the first 11 years, determine whether this new elk population in the GSMNP will survive, and to create a plan that the Park Rangers can implement to improve elk population over time.

2 Assumptions

1. Elk deaths by poaching, accident, predators, and unknown reasons cannot be caused by environmental conditions.
2. Of the remaining elk deaths and births, the only environmental factors that could relate to elk death or birth rate are temperature, precipitation, ozone levels, particulate matter, water quality, and humidity.
3. Elk deaths by poaching and accidents, and unknown reasons stay in proportion to the population every year.
4. The food source of the Manitoba Elk is entirely grass.
5. Black bears are the only non-human predators of the Manitoba Elk.
6. Black bear population in the GSMNP is proportional to black bear population in the North Carolina mountain region as a whole.
7. Elk grazing does not significantly kill the grasslands. Instead, an equilibrium population is reached.

2.1 Rationale for Assumptions

1. Except under extreme weather situations, which are rare in the GSMNP, humans and predators do not attack or accidentally kill based on the aforementioned environmental factors. A poacher will not stop at killing an elk because the temperature outside has dropped several degrees.
2. For elk population statistics that could be related to environmental factors, the factors are either major components of climate or directly related to environmental pollution. Furthermore, these are the environmental factors that the National Park Service has decided to monitor in the GSMNP.

3. These human-related events have occurred with little frequency since the reintroduction of the elks, rendering any correlation analysis unreliable. We reasoned that they vary with the population, as greater/lesser elk population means a higher/lower chance of contact with humans. Since we have no knowledge of the nature of unknown deaths, it is impossible to speculate as to their causes or attempt to predict them in the future. Therefore, we will assume that these stay in proportion to the population.

4. While the Manitoba Elk does feed on substances other than grass in its native environment, grasses make up the majority of its diet. [1]

5. Elk in the GSMNP are targeted by black bears, bobtail cats, and coyote. However, black bears play by far the largest role in elk predation. [1]

6. The data used for bear populations is from the total black bear population in mountains in North Carolina. Since the mountain region of North Carolina is relatively small and the GSMNP is a subset of this region, we can safely assume that the mountain terrain of North Carolina is similar to the mountain terrain of the GSMNP. Thus, the GSMNP black bear population is probably spread in a manner similar to that of the North Carolina mountains.

7. This assumption is based off the Yellowstone elk population, which has reached an equilibrium of about 30,000 elk during summer grazing months.

3 Problem Analysis

3.1 Background

We first isolated some of the key problems in establishing a permanent elk population in GSMNP [1].

Elks experience predation. Out of all the deaths that occurred since the initial introduction of the elks, 25% of those deaths were predation related. Additionally, all of the predation deaths can be attributed to the black bear. In the future, predation will likely play an important role in determining whether the elk population will persist, so this is a problem that must be addressed.

Death caused by disease was responsible for 37% of all deaths since the initial introduction. Most adult elks die from the Meningeal Worm, a parasite carried by white-tailed deer. Since the white tailed deer population has remained fairly constant in the GSMNP region, determining how to control the interaction between the elk and white deer populations, or more importantly, the Meningeal Worm, is of utmost importance.

Elks prefer to graze on open grasslands, which constitute only 1-3% of GSMNP. With such a small proportion land being optimal for the elk, it is key to understand how to maximize the carrying capacity of the elk population in GSMNP.

Most of the elk diet consists of grassland plants, which are impacted by abiotic factors such as air and water quality. Elk births, which occur in the spring, are heavily dependent upon the health of female elks during the summer. Ground level ozone may damage grassland plants that elks eat and may have negative effects on the reproduction rate of the elks. Establishing a plan for long term elk population must consider these abiotic factors.

Elks may wander off the GSMNP area and into territories that are not monitored. Elk-human interactions have resulted in the death of several elk, all attributed to vehicle accidents. Elks have also grazed on private grasses outside the GSMNP zone, which may put them to predators outside the region. Some events have required the park personnel to remove the elk and in some cases, euthanization.

3.2 General Procedure

The problem concerns both the survivability of the Manitoba Elk and a follow-up plan for long term elk growth. We will first discuss our theoretical calculations for the future Manitoba Elk population, which took into account all factors that we determined were correlated to the Elk's survival. Next, we will discuss our our plan to improve long term elk growth, with the ultimate goal being to establish a permanent elk population at GSMNP.

In order to understand the dynamics of the elk population over time, we had to understand both how the elk population grew and what factors had a significant influence on the elks. The primary goal was to find a quantitative relationship between the elk population and a variety of factors including water quality, predation, and sickness. For all variables that we determined could possibly have an effect on the elk population, we retrieved the available data, and analyzed them for correlation. In this study, we took into account the following variables as summarized in Table 1.

Abiotic Factors	**Predation-related Factors**	**Disease-related Factors**
Air pollution	Black Bears	Chronic Wasting Disease
Ground ozone levels		Bovine Brucellosis
Climate		Cerebrospinal Encephalitis
Water Quality		

Table 1: Factors influencing elk population

In the analysis of our predicted GSMNP elk population, we were then able to make several recommendations that would improve the growth rate of the elk population. Since we possessed the predicted elk population as a function of predation, disease, and vegetation factors, implementing active monitoring activities to keep elk population factors within designated desirable ranges were directly addressed.

A significant source of useful groundwork was the FONSI for Environmental Assessment for Establishment of Elk in Great Smoky Mountains National Park [1], an outlined plan to sustain the elk population through environmentally agreeable means. While this study provided great insight into potential variables that could be included and excluded it lacked the quantitative basis, which was the aim of our study. Some variables that we excluded through recognition of the FONSI plan were human interactions (e.g. accidents with vehicle collisions) and the accidental introduction of a severely sick elk into the population, an extreme case in which the elk population would have to be killed to contain the disease.

4 Model Design

The theoretical model that predicted the elk population over time depended on how individual factors influenced the elk population over time. Thus, we had to model, for example, the predator-prey relationship between black bears and elk and predict how many bear attacks would kill elk each year. After finding the time dependent model of each relevant factor, we used both a logistic growth model and a predator-prey model to find the number of elks present in the permanent GSMNP population.

4.1 Definitions of Variables

1. E = elk population
2. B = black bear population
3. α = efficiency for the bear to convert an elk death into a bear birth
4. β = rate of elk death per encounter $\times$ constant of proportionality of encounter
5. G_E = growth rate of the elk in the absence of predation
6. G_B = growth rate of bears in absence of elk
7. K_E = carrying capacity of the elks
8. K_B = carrying capacity of the bears
9. Si = proportion of total elk population that die each year to sickness
10. A = Ammonium concentration (μeq L^{-1})
11. S = Sulfate concentration (μeq L^{-1})
12. t = years since 2001 elk introduction

4.2 Abiotic Factors

We examined abiotic variables that could have significant effect on the ecological system of the GSMNP. Hourly data on precipitation, ozone levels, particulate matter, water quality, and humidity during the time period January 1st, 2001 to December 31st, 2011 was obtained and averaged over the period of each year [2]. These dealt with air pollution and water quality. Hourly data on temperatures was also obtained and averaged for the corresponding summer and winter seasons for climate. See Appendix A for averaged yearly abiotic factors.
The abiotic factors were tested for correlation with elk births and deaths. The highly correlated values, determined using the p values, are shown in Table 2:

Based on these correlations, we determined that water quality, and more specifically ammonium concentrations in precipitation and sulfate concentrations in streams, was related to elk populations through sicknesses. Ammonium and sulfate are harmful to most animals in streams in relatively high quantities, and its correlation concurred with our analysis of the meningeal worm, as discussed more in-depth in Disease section.

	Total Deaths	Sickness Deaths	Predator Deaths	Births
Winter Temp	-0.526	-0.403	-0.329	-0.063
Summer Temp	-0.036	-0.296	0.453	0.257
Precipitation	0.187	0.308	-0.196	-0.428
Ozone	-0.447	-0.134	-0.275	-0.12
Particulate Matter	0.155	-0.207	0.702	0.465
Humidity	0.352	0.315	0.009	-0.225
Nitrate Throughfall	-0.094	-0.435	0.329	0.574
Nitrate Precipitation	0.270	0.189	-0.148	-0.058
Nitrate Stream	-0.665	-0.280	-0.510	-0.031
Ammonium Throughfall	0.109	-0.405	0.691	0.638
Ammonium Precipitation	-0.748	**-0.885**	0.336	0.706
Ammonium Stream	0.296	0.160	0.063	0.009
Sulfate Throughfall	-0.300	-0.686	0.617	0.687
Sulfate Precipitation	-0.577	-0.764	0.179	0.628
Sulfate Stream	**-0.775**	**-0.970**	0.355	**0.794**
pH Throughfall	-0.576	-0.215	-0.104	-0.250
pH Precipitation	-0.056	0.080	0.239	-0.358
pH Stream	-0.274	0.030	-0.003	-0.329

Table 2: Table of correlation values of abiotic factors with elk population statistics. Significant correlations have been bolded.

Using our correlations, we performed multiple linear regression, using ammonium and sulfate concentrations as the predictor variables and deaths from elk sickness as the response variable. The equation of the line is:

$$Si(A,S) = 0.4977 - 0.001522A - 0.01524S \tag{1}$$

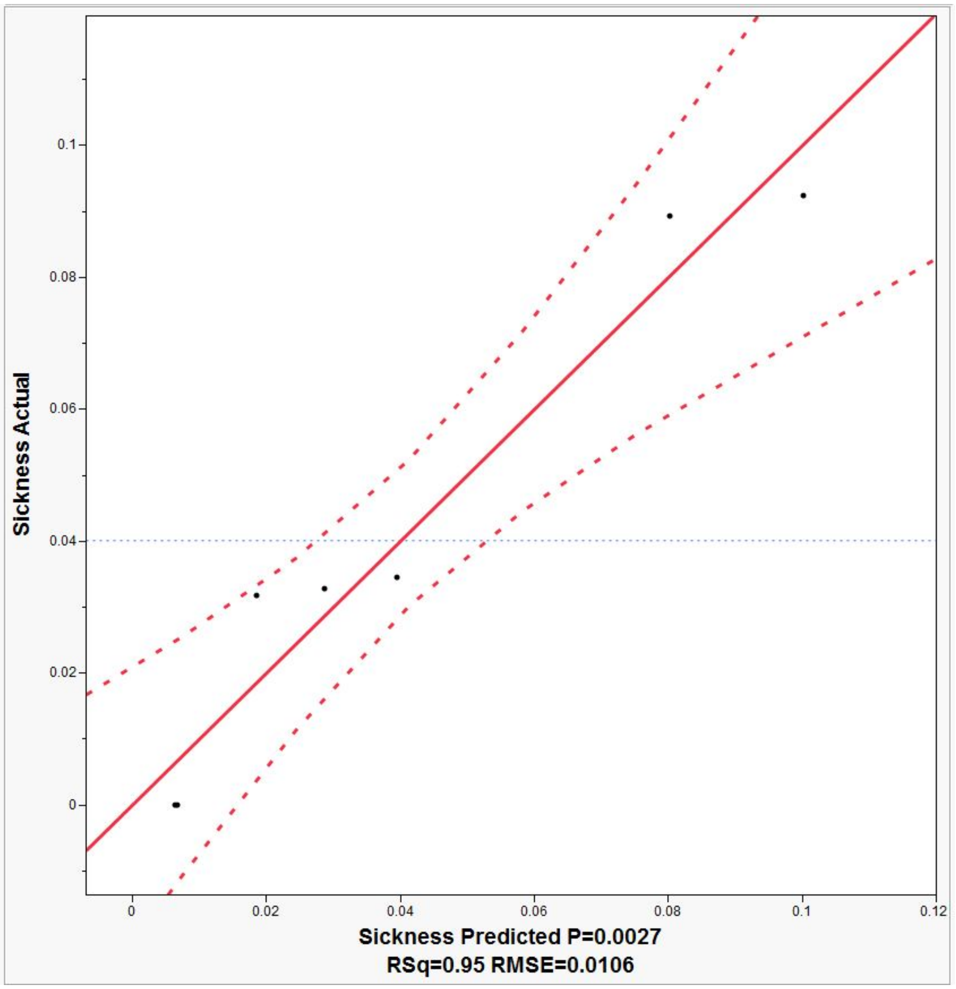

Figure 1: The multiregression results based on Eq. 1. P = 0.0027 < 0.05

4.3 Predation

Predators of the elk include wolves, bears, and mountain lions. However, only the black bear population is significant in the GSMNP region and has large contribution to the total identifiable calf mortalities (65%) [1]. Thus, with the black bear as the main elk predator, we utilized both the Lotka-Volterra and logistic growth models for the black bear and elk to determine how predation would impact the elk population. The model that we used was the following:

$$\frac{dE}{dt} = G_E E - \beta EB \tag{2}$$

$$\frac{dB}{dt} = \alpha\beta EB + bB \tag{3}$$

Data on the total bear population from 1980 to 2007 in the mountain regions of NC was taken from the North Carolina Wildlife Resources Commission [3]. By scaling the total mountain population of black bears by the total area of GSMNP to the total mountain range area of NC, we found the total population of black bears in GSMNP from 1980 - 2007. This was fit to a logistic growth model (equation 4).

$$B(t) = \frac{K_B B(0) e^{G_B t}}{K_B + B(0)(e^{G_B T} - 1)} \tag{4}$$

Where $K_B = 303, B(0) = 70, G_B = 0.0839$, as determined by regression fitting. Using this model, we found the values for the theoretical black bear population past 2007, as shown in figure 2.

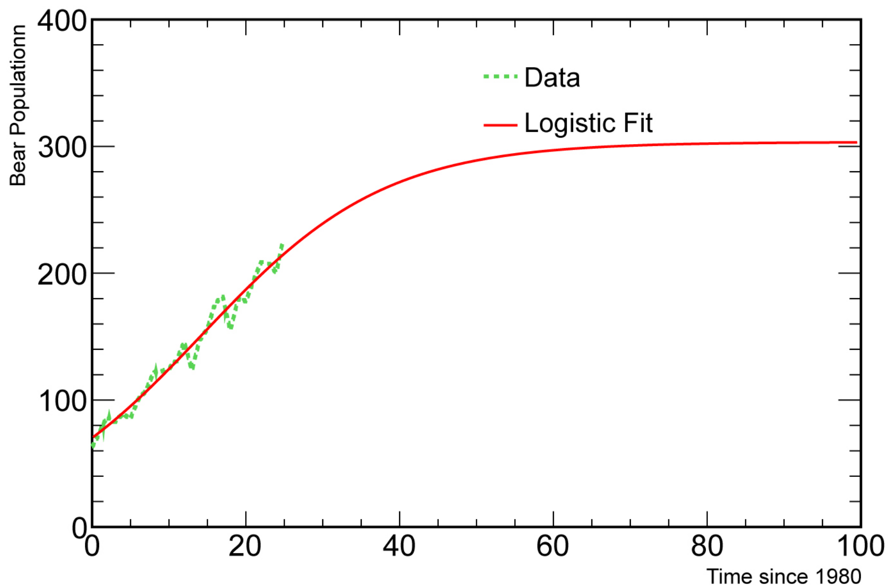

Figure 2: The bear population curve in GSMNP, as determined by regression fitting to the logistic growth model (Eq. 4)

After finding the bear population, we found the rate of change in the elk population. We did this by averaging the fractional increase in the elk population of the previous year to the population of the current year added to the number of elks that were killed by predation. This would exclude the effects of predation from one year to next. Also, we only examined the growth rate during years that did not have artificial elk introduction (all years except 2001, 2002, 2007).

Next, we found the death rate of elks due to predation. We can derive Eq. 5 by assuming the number of elk-bear encounters are proportional to both the number of elk and the number of bears (as assumed already by the Lotka-Volterra equations). We averaged the proportion of elks to die from predation across all years. Based on our model of bear population, we then determined β for each year, then averaged these values. (Eq. 5).

$$\begin{aligned}
\text{encounters} &\propto EB \\
\text{deaths} &\propto \text{encounters} \\
\text{deaths} &= \beta EB \qquad (5) \\
\text{deaths}/EB(\text{averaged}) &= \beta \qquad (6)
\end{aligned}$$

The carrying capacity of the elk was calculated by analyzing the carrying capacity of the elk population in Yellowstone National Park (YNP) [4]. By scaling the YNP elk carrying capacity by the total area of grassland in GSMNP to the total area of grassland in YNP, we found the GSMNP elk carrying capacity. However, since we wanted the carrying capacity sans predation and disease, we adjusted the Yellowstone carrying capacity as such. Literature has shown that predation death rates in calves, which in the GSMNP data accounted for 100% of predation deaths is 65.6% [4]. Furthermore, calves make up about 25.45% of the population, based on the population statistics given in the problem statement. This is justified because the elk diet heavily consists of grassland plants, as shown in table 2.

Food	**Composition of elk diet**
Grasses	66%
Forbs	11%
Sedges/Rushes	9%
Conifers	5%
Shrubs	4%
Ferns	4%
Other	1%

Table 3: Fecal analysis demonstrates the composition of elk diet in the Cataloochee study area, GSMNP, NC. Data was averaged over 2003-2005 [1]

The last parameter that we had to consider as input to our modified lotka-volterra logistic model was the efficiency of converting an elk death into a black bear birth. After considering a reasonable range for this parameter, we were able to find the predicted effect of predation on the elk population in the future at GSMNP.

4.4 Disease

Chronic Wasting Disease (CWD) is caused by infectious prions. It is spread by feeding on grass grown in contaminated soil. Although prevalent in the western plains of the United States, it is not widely spread in the eastern mountain regions. In fact, there has not been a reported case of CWD inside or near GSMNP [5] Furthermore, the elk introduced into the GSMNP were completely healthy. Therefore, we can safely rule out CWD as a factor of elk sickness.

Brucellosis is caused by several bacteria of the genus Brucella. It is highly infections, spread by the bodily fluids of cattle, bison, and small mammals. However, strains related to the the elk, B. abortus, have been eradicated from the eastern United States. B. abortus is still present in some regions of Greater Yellowstone National Park [6]. Again, as the elk introduced into the GSMNP were completely healthy, we can rule out Brucellosis as a possible elk sickness.

Cerebrospinal encephalitis is directly caused by the meningeal worm, an infectious parasite that uses snails as intermediate hosts. According to [1], all deaths by sickness in the experiment were due to cerebrospinal encephalitis, so we know it is the single most significant factor. Elks become infected from white-tailed deer contact, and the white-tailed deer, in turn, are infected by consuming the snails. We reasoned that total populations of snails was a major factor in determining the sickness of elks. Snail population itself is closely related to water quality of streams, since snails primarily inhabit damp regions. Water quality was therefore the primary component of elk health. [7]

4.5 Final Model

After analyzing the individual effects of predation and abiotic factors on the elk population, we analyzed how all of these effects, in addition to random variables, such as poaching, would collectively influence the elk population.

Now, we have 3 models which each independently describe some aspect of the Elk's population trends. The most general and easily modifiable ones of these is the predator-prey Lotka-Volterra model:

$$\begin{aligned}\frac{dE}{dt} &= G_E E - \beta EB \\ \frac{dB}{dt} &= \alpha\beta EB + bB\end{aligned}$$

One of the terms in the elk's equation, $G_E E$, determines the growth rate of the elk in the absence of the bears. However, we determined some of the statistics for bears based on a logistic growth curve, which has also been shown to model population statistics accurately in the past. Therefore, we make a substitution which incorporates the logistic growth model into the Lotka Volterra:

$$\begin{aligned}\frac{dE}{dt} &= G_E E(1 - E/K_E) - \beta EB \\ \frac{dB}{dt} &= \alpha\beta EB + G_B B(1 - B/K_B)\end{aligned}$$

One more thing that we have found to have an effect on elk population is death by sickness. We have found a correlation between elk sickness rate and sulfate and ammonium concentrations. Because this is the elk death rate, we may add another factor to the elk's modified Lotka Volterra + Logistic equation, which is the population of elk mulitplied by the death rate of the elk due to sickness, which will yield the total change in elk population due to sickness. After this addition, we have the final equation which can be solved numerically to yield the elk population curve over time:

$$\frac{dE}{dt} = G_E E(1 - E/K_E) - \beta EB - E(0.4977 - 0.001522A - 0.01524S) \tag{7}$$

$$\frac{dB}{dt} = \alpha\beta EB + G_B B(1 - B/K_B) \tag{8}$$

All of these factors were unrelated to each other. For example, predation occurs independently of poaching and accidents occur independently of abiotic variables. Thus in calculating and predicting the change in population in any given year, we could simply add together the effects determined by each of these factors.

5 Model Analysis and Results

Based on our final model of the elk population in GSMNP, we were able to predict that the elk population would survive as a permanent population. Our conclusions are summarized in the graph below (figure 3).

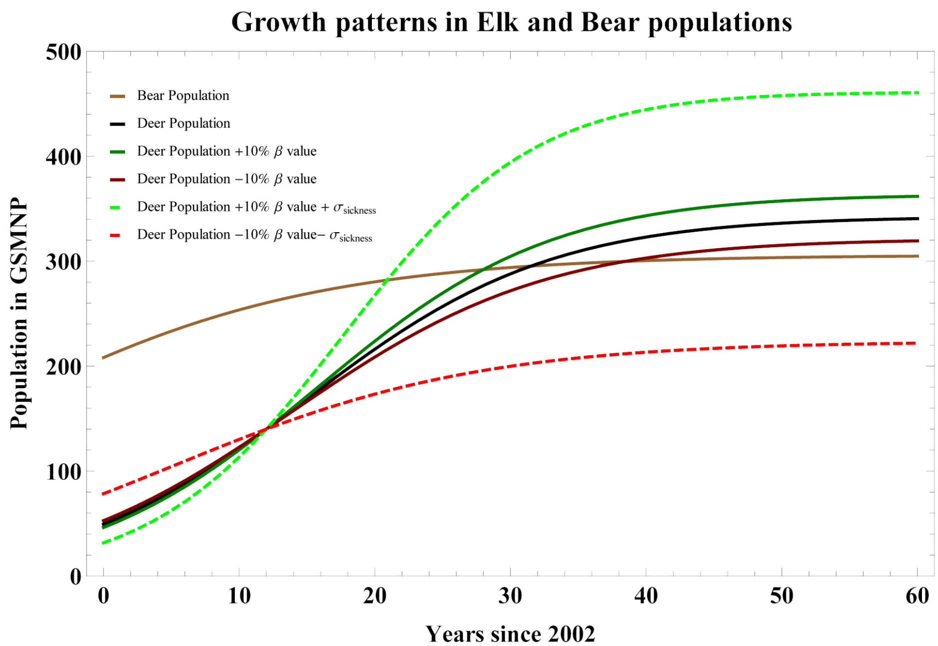

Figure 3: The bear and elk population curves in GSMNP, as determined by numerical solutions to our final model (Eqs. 7, 8), along with curves representing extreme high and low values (1 standard deviation of sickness and a 10% change in estimated β value compounded.

The plot was generated with a value of $\alpha = 0.01$. There are no significant changes in the predicted equilibrium populations for $\alpha \in [0, 0.1]$, so we concluded that our model is insensitive to reasonable changes in α.

In figure 3, the red dotted line may be interpreted as the worst case scenario, while the green dotted line may be interpreted as the best case scenario. These ranges in the deer population resulted in inputting a range of values for the sickness factor (which was a function of ammonium and sulfate concentrations) and α.

From the large statistical uncertainty in the sickness related deaths, which was calculated as a function of the uncertainties in the ammonium and sulfate concentrations, it is seen that the changes in the sickness factor for the elk population alter the equilibrium population. We found that changing α by 10% resulted in little difference.

Parameter Values	Conditions	2020 Population	2060 Population
Expected	Average sickness, average β	225	340
Worst Case Scenario	High sickness (+1 σ), increased β by 10%	177	222
Best Case Scenario	Low sickness (-1 σ), decreased β by 10%	284	460

Table 4: Table of values for predicted 2020 and 2060 elk populations at expected, worst case, and best case scenarios.

6 Elk Growth and Improvement Plan

Our elk growth and improvement plan is a response to undesired values of inputs for our final model of elk population growth over time. Population was predicted to stabilize over time, so we decided minimize human interaction to let nature take its course. Thus, the plan described will not include a timeline for the next decade, only responses to several conditions monitored in the GSMNP.

6.1 Elk Population Monitoring

There are several ways to measure elk population in GSMNP. Complete counts, incomplete counts, and mark-and-recapture methods are common methods for elk and other large ungulates. [8]

A complete count tallies every member of the population for an area by forced herding of the animals or aerial sightings. An incomplete count tallies part of the population and the area that it inhabits, and extrapolates the data to the entire known population range. Finally, the mark-and-recapture method involves marking a portion of the population, releasing it, and recapturing a different portion at a later time to count the number of marked animals.

We suggest combining complete counts, with mark-and-recapture as a supplemental method. Since elk are larger animals that are currently in smaller numbers in GSMNP, it is feasible to do a complete count using aerial sightings [9]. This will ensure an accurate estimation, if not actual population number. In cases of large elk growth or unfavorable weather conditions, we will turn to mark-and-recapture. It is extensively used to estimate fish and game populations [10]. While it is helpful, there are large number of assumptions in this method: marked individuals behave the same as unmarked individuals, marked individuals are caught at the same rate as unmarked individuals, marked and unmarked individuals mix evenly, etc. Complete counts, with no assumptions and easy execution with small populations, is therefore preferred to mark-and-recapture.

6.2 Sulfate and Ammonium Concentration Monitoring

In our study, we found a significant correlation between the sulfate concentration in streams and the ammonium concentration in precipitation. As mentioned above, high concentrations of sulfate leads to the death of snails, the intermediate host of the Meningeal Worm, which is the primary cause for sickness related deaths for the Manitoba Elk. Using our multiple linear regression model that relates the proportion of the total elk population that dues to sickness with ammonium and sulfate concentrations, we found the critical range of values for ammonium and sulfate that would correspond to less than a certain proportion of sickness related deaths. A plot below depicts the critical set of values for ammonium and sulfate concentration for various proportions of sickness related deaths.

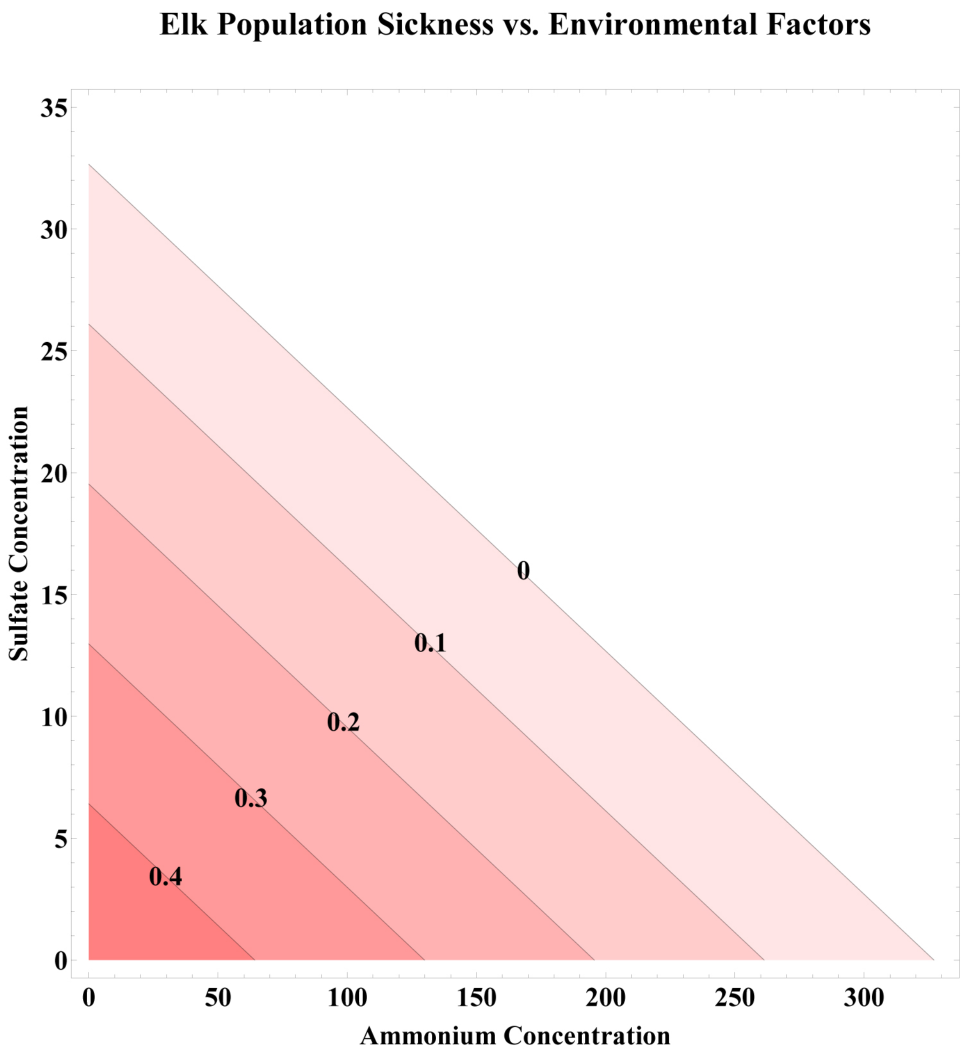

Figure 4: The range of allowable sulfate and ammonium concentrations plotted to reveal the expected death percentage in elk population.

Unfortunately, sulfate has a proven adverse effect to the stream ecosystem. However, given the fact that the strong negative correlation between sickness and sulfate, we can infer the importance of controlling the snail population in streams. Thus, we propose that controlling the snail population in streams to small numbers can decrease the number of elks that die of sickness related causes each year.

6.3 Black Bear Population Response

Bear populations are linked to elk populations through the predator-prey model used. If bear populations were to increase beyond our predicted amounts, elk may start to die off at a faster rate. We would thus focus on bear population control. A commonly used approach is permitting the hunting of black bears in season [11]. Hunters with licenses would be allowed to kill a certain of bears, with the number corresponding to amount of overpopulation. Bear relocation is also used, moving bears from primary calf birth areas to other regions. This has been shown to be effective [1]

An alternative method that is gaining traction uses contraception and sterilization methods to prevent pregnancies. These have the advantage that they are non-invasive and a one-time operation, simplifying the procedure of population control without greatly harming the bears. However, they are also more expensive and time consuming than euthanization. [12]

A last resort would be the trapping and euthanization of bears. This method is used only on problematic bears, in accordance to the standard bear management procedures. Problem bears are ones that have resisted all other techniques to deter them from human settlements. This includes chemical repellent, fencing, and aversive conditioning. [11]

We recommend a combination of hunting encouragement, relocation, and immunocontraception/sterilization. Hunting and relocation provides short-term decrease of the bear population, and can be relatively easily supervised and modified. Sterilization would be used in situations of quickly growing overpopulation. One sterilized male will be unable to reproduce for the rest of his life, and immunocontraception of a female would stop any pregnancies for five years. These would have a more longer lasting effect compared to hunting.

7 Conclusions

In our study, we predicted the number of elk in GSMNP following the eleven year initial introductory period from 2001 to 2011. After determining which environmental factors would impact the elk growth rate the greatest, we took the collective effects of these factors to generate a model for the elk population, which was based on both the Lotka-Volterra and logistic growth models. Our model predicted that the elk equilibrium population, which was reached in about 2060, was for the best case scenario, 460 elk, or for the worst case scenario, 220 elk.

Our model utilized the correlation between sulfate concentration in streams and ammonium concentration in precipitation, which likely resulted from the detrimental effects of the parasitic Meningeal Worm-Manitoba Elk relationship. A strength of our model was that it modeled elk sickness as a function physical environmental variables. Another strength of our model was its direct application to the elk growth plan. We were able to find the values of input parameters, such as the relative encounters of bears and elk, that could be constrained based on the desired equilibrium population of the elk. Thus, our model directly supports the conclusions made in our elk growth improvement plan.

Possible areas of improvements included considering more data (beyond 2011). In this study, we based our model off of provided values (e.g. birth, death, sickness). However, there may have been significant residual effects in the data that may have resulted in significant variance in the presented table values. We were not able to quantify these residual effects and thus realistic error bounds for our conclusions could be entirely reached. However, with the inclusion of more data, this can be fixed.

8 Letter to Commissioner of the Department of Wildlife:

To the Commissioner of the Department of Wildlife:

More than a century ago, the eastern elk population in Native America went extinct. As you may know, recent efforts have led to a program that introduced a small population of the Manitoba Elk into Great Smoky Mountain National Park (GSMNP). We have conducted a study on the recently introduced Manitoba Elk population in the GSMNP and have determined that this elk population will survive and continue to proliferate. In addition to this, our study provides insight to important factors on elk population growth and has helped us generate a improvement plan to optimize the growth of the elk population. Our model took into account a wide array of available data and may be considered in future action plans regarding the Manitoba Elk species preservation.

We examined the elk births and deaths by poaching, sickness, accident, predators, and unknown causes. We also obtained data of the following influential abiotic factors: temperature, precipitation, ozone levels, particulate matter, water quality, and humidity, all of which are important to air or water quality. Predator populations and causes for sickness were incorporated and correlated with the data, leading us to a mathematical growth model. In addition to showing that the elk population would survive, the model showed a stabilization of elk population in about 2060 of 322 individuals.

The study concluded two major factors in the health of the elk population: sulfate and ammonium concentrations in streams and precipitations, respectively; and black bear population. We observed that larger amounts of both sulfate and ammonium led to less elk illnesses. We also discovered that the black bear, a predator of elk, had significant contributions to elk deaths. Thus, our elk growth and improvement plan centered around these components.

Because the population was predicted to stabilize over time, our growth plan is not so much a structured timeline of active management as a response to unfavorable conditions. We suggest monitoring the sulfate and ammonium concentrations in streams and precipitation. We related values for the concentrations of sulfate and ammonium with disease-related deaths, which can be used to determine a reasonable range to maintain the elk population. If values are outside the range, various chemical or natural agents can be introduced in the environment in attempt minimize the change. We also recommend keeping track of black bear population in relation to the elk population. If black bear populations grow far beyond our predictions, it may be necessary to implement population control measures. The most effective ways would be a combination of hunting encouragement, relocation, and immunocontraception / sterilization. Hunting and relocation provide short-term decrease of bear population, and are simple to supervise and modify. Immunocontraception/sterilization would provide a means of long-term population control with little harm to individual bears.

Our study concludes a positive trend in elk growth in the GSMNP. With our growth and improvement plan, we will be able to maintain a strong elk population for years to come.

Sincerely,
Team 3422

9 References

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