Stabilizing Elephant Populations through use of Contraceptive Dart

Claire Homer
Sergey Magedov
Yash Shah
Tanner Thorton
Alyssa Wilson-Baxter

November 4, 2019

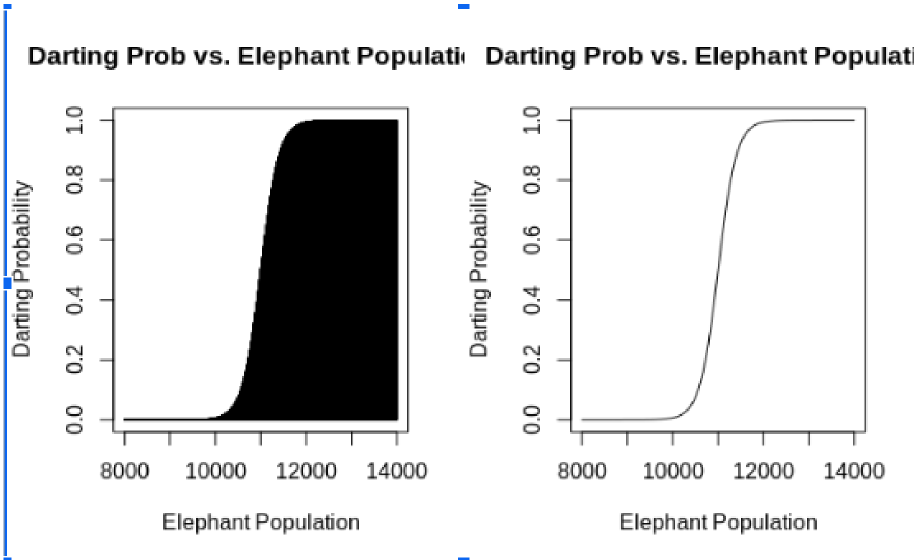
Abstract

The purpose of this project is to develop a model to limit the population of elephants in large national parks in South Africa to 11,000 by using contraceptive darts. The logistic darting model used will predict the survival rate of elephants between the ages of 2 to 60 and estimate how many elephants would need to be darted each year to fix the population to 11,000 elephants. Our model would be applicable to parks with elephant packs ranging from 300-25,000 that have differing elephant survival rates. However, contraceptive darting has been very controversial due to concern that if the elephant population were to drastically decrease from poaching or disease then the population would be unable to recuperate.

Terminology

Logistic Distribution

In probability theory and statistics, the logistic distribution is a continuous probability distribution. Its cumulative distribution function (Sigmoid function) is the logistic function, which appears in logistic regression. It resembles the normal distribution in shape but has heavier tails.



ReLU (Rectified Linear Unit) Function

The rectified linear activation function is a piece-wise linear function that will output the input directly if is positive, otherwise, it will output zero. It has become the default activation function for many types of neural networks because a model that uses it is easier to train and often achieves better performance.

Predictive Expected Adjustment

The defining functional effect of these technical approaches is that predictive analytics provides an expected value baesd on the probability in order to determine, inform, or influence organizational processes that pertain across large numbers.

Introduction

Due to decades of poaching and disease, South African elephant populations have drastically decreased. As a response to this issue efforts were made to nurture elephant populations which resulted in elephant overpopulation. Since the elephant population is thriving parks are faced with the dilemma on how to control the population. The most common forms of maintaining a fixed population is through culling, relocation and darting (Bertschinger et. al, 2013). Killing the elephants has been controversial, therefore making this method unacceptable. Some argue that this way individuals can profit from the resources elephants give, such as ivory (Bradshaw et. al, 2013).

Ideally the relocation of elephants seems to be the best method but realistically it comes with problems. The first is that the process of capturing the elephants can be stressful and dangerous for humans and elephants. It requires a crew with skills and experience, it is also very expensive and reserves lack the financial means. The second problem is that there are only a few areas large enough to receive them and allow for population growth (Faust et. al, 2013). The problem of maintaining a population is then transferred to smaller reserves that accept these relocated elephants. The third problem is the effects of relocation on elephants. Male elephants entering adolescence become quite dangerous and deadly for other animals (Archie et. al, 2012). Researchers have monitored the relocation of 12 elephants for a period of three years. These elephants were fitted with a GPS collar that tracked their location every 4 to 8 hours. These elephants were then classified into three groups. The first group was for those who tried to return to their original stomping grounds. The second group was for those who left the reserve and wandered. The last group was for those elephants that stayed at the new reserve. Only 3 of the 12 elephants stayed but became problem elephants (Butler, 2011). Overall relocation of elephants temporarily solves the problem in one park, but then creates problems for others.

Over the past fifteen years scientists have been doing research on a more innovative and effective method of managing elephant populations, by using the contraceptive dart. This method has been reported to safely and successfully controlled elephant populations. The contraceptive dart is also known as the immunocontraceptive vaccine and works by producing antibodies within the elephant to prevent fertilization, without the side effects of hormonal contraceptives (Fayrer et. al, 2012). There are numerous reasons why the contraceptive dart is a good solution. First, it's incredibly effective; the vaccine has been tested in everything from stray cats to voles to African elephants (Archie et. al, 2012). Second, the vaccine has no behavioral side effects. If male elephants are darted by accident, they won't be affected at all. Moreover, a female who is darted several times will have no side effects and still be protected from conception (Bradshaw et. al, 2006). The antibodies that are produced persist in the female elephants body for twelve to fourteen months.

Scientists of the Amarula Elephant Research Program in Durban in conjunction with several national parks in South Africa, have developed a schedule for contraceptive darting that would halt elephant population growth. Initial trials of the contraceptive dart used 41 female elephants to test the efficacy of the dart (Kerley et. al, 2007). These elephants were located from a helicopter and determined to not be pregnant with the use of an ultrasound machine and blood tests through aerial darting. Only twenty-one elephants were given the contraceptive dart while the other twenty were given a placebo (Maisels et. al, 2016). These elephants were then placed in a family unit. The elephants were monitored for twelve months using numbered radio collars. When the twelve months were over the elephants were tested for pregnancy. Nine of the elephants darted with the contraceptive were pregnant, one having been pregnant before getting darted with the contraceptive. This elephant gave birth to a healthy calf demonstrating that the contraceptive dart has no effect on gestation, the fetus, or parturition. Sixteen of the elephants darted with a placebo were found to be pregnant. This model did not demonstrate the efficiency of the contraceptive, however it did show that the contraceptive dart has no effect on an already pregnant elephant or the fetus. Of the elephants, 44% were pregnant (Fayrer et. al, 2012 and Lange et. al, 2013).

Following this, the scientists used ten elephants in a revised schedule as a guide for darting. The elephants were darted with an initial vaccination, then identical boosters were delivered from a helicopter two and four weeks later. The elephants were again tracked with radio collars for twelve months and placed among family units. When the twelve months were over, the elephants were tested for pregnancy and only two were deemed pregnant. The amount was halved to 20% compared to the previous model (Bertschinger et. al, 2013). Also from the use of the radio collars, it was determined that female elephants not separated from the family unit did not experience abnormal behaviour (Smith et. al, 2006). Five additional darted elephants elephants were kept for observation, separated from the family unit. After eight months these elephants started showing abnormal behavior (Garrot, 2006). This time the model used for darting was more efficient and managed the population well. After determining that this way of darting the elephants was indeed more effective, they then preceded to test the reversibility of the contraceptive.

Of the previous ten elephants the eight that were not pregnant were used again to determine whether the effects of the contraceptive were reversible. Four were again darted with the immunocontraceptive while the other four were not. Twelve months later the elephants were again tested for pregnancy. The four that did not receive the contraceptive dart were pregnant, while the four that received the contraceptive dart were not pregnant (Ferreira et. al, 2006). This demonstrates the fact that the effects of the dart are reversible and do not cause any harm to the elephant nor prevent it from reproducing again. The model used for contraceptive darting in this case, demonstrates that it is effective enough to utilize on elephants to manage population sizes without killing or relocating them.

Elephant density is a positive predictor of the annual number of visits a park in South Africa receives. Approximately across Africa the annual, direct economic losses from reduced tourist visitation due to elephant poaching run to a mean of 9.1 million USD with an additional mean loss of 16.4 million USD in indirect and induced spending (Hanley et. al, 2009). These estimates represent the first country-wide assessment of the economic losses that the current elephant poaching surge is inflicting on the nature-based tourism economy of South Africa. Using a central figure of 25 million USD in lost economic benefits per year highlights the relative impact of these losses: this represents close to 20% of the receipts from all tourist visits in South Africa (Keane et. al, 2008).

On the other hand, the economic difficulties of elephant conservation are also illustrated by the fact that annual losses to tourism are only a small fraction of the estimated 597 million USD that ivory from Africa's poached elephants was worth annually on Chinese black markets (Wasser et. al, 2010). Despite the recognized importance of Africa's natural assets, especially wildlife, to tourism and other development pathways, expenditures that tourists make during park visits and the associated impacts local economies.

Approach

The main approach takes into consideration that population updates need to be made every year. Each year the elephants need to be counted, and if the population exceeds 11,000 elephants or a desired population, they are only darted. This model implements probability as a mean of darting the female elephant population.

P(darting a female elephant) = $\frac{1}{1+e^{\frac{x-\mu}{\sigma}}}$

Where,

x is the total population where pregnant elephants are counted as 2 elephants.

μ = 11,000, which is the desired population that is a hyperparameter.

σ = 200, which is the scale of the population.

The probability comes from the CDF of the logistic distribution which is also known as the Sigmoid function in Machine learning. The important aspect of darting is that we can change the scale of distribution to make sure that population lies between certain range. For us, the convergence occurs, but the variability of the population lies between 9,000 and 13,000. There are two approaches to be considered while darting pregnant elephants. If a pregnant elephant is darted this model takes into consideration that the fetus will be born without any complications or it will die. Currently the model is set up to make pregnant elephants abort if they are darted. From this we can conclude that darting is extremely effective for managing elephant populations long term.

The program starts with initializing elephants dynamically from an excel file that was provided as the transported elephant list. The reason behind implementing this is under the assumption that elephants that are transported out will start a new life in a different park away from their original population. We use the equation 4*(Transported elephants from Year 1) + 4*(Transported elephants from Year 2) to initialize the elephant population. Since the darting controls the population size, regardless of the final population, the population size of interest is around 11,000 elephants. It is necessary to understand that darting has certain repercussions. By enabling fetuses to be aborted when pregnant elephants are darted, the distribution of ages changes. The population then ages faster and newborns aren't taking their predicted places. At a certain point the elephant population will have shifted to different ages.

Relocating elephants is an effective way to control populations as well. However it is unnecessary to spend large sums of money to relocate elephants. In order to take into consideration relocating the program generates a random sum of between 600 and 800 elephants across all the age-structured population in the function randfixed.m (Stafford, 2006). Darting and Relocation of elephants are being considered as two separate parameters. Results from this model are included in fixed years pertaining to how the age-structure changes as well as the total number of elephants. Furthermore, this model considers in the file Elephant.m, elephant class which represents each elephant individually including year, their age ,and whether it is pregnant. It also includes its reproductive capacity and whether the elephant will die of natural causes. The file ElephantControl.m provides a data structure that controls the way elephants are darted, and keeps track of their reproduction, death, and age. Moreover, this model is sustainable for up to 1,000 years.

This model was the most plausible. The models takes into consideration two physical consequences from darting a pregnant elephant, abortion or a healthy delivery. Since either option can be chosen, the model can modify itself in accordance to the biological consequences of the dart being used. Hence if the dart has side affects the the fetus it is accounted for, or it can be switched and account for darting that is harmless to the fetus. The model also implements killing and relocating elephants. Since relocating elephants is a financial burden to most parks, the model generates a random amount of elephants (between 600-800) to be relocated each year. The model keeps track of changes in age structure, elephants' age, whether the elephant is pregnant, the elephants' reproductive capacity, and how and when the elephants will die. The way elephants are darted is controlled and when an elephant reproduces or dies it is monitored. Thus making this model the most reasonable for maintaining elephant populations within a desired range. Also, it is simple to explain to park management, and it monitors aspects that need to be considered in order to manage elephant populations.

Alternative Approaches

The first approach, an Expected Predictive Adjustment Model, determines the number of darts to fire, the expected number darted and the new model for each iteration to maintain a population of 11,000. The model calculated the survival rate, the target population, and approximate population to estimate a future population of around 11,000 elephants. The approximated population is multiplied by the survival rate to give the current population of the first year. The current population thereafter is calculated by finding the difference between the previous population and current population. A 70 by 10 matrix was created, were the rows contain the age structure of the elephants, 1 year old to 70 year old. Column 1 is the population of elephants corresponding the ages of the elephants. Columns 2 to 8 represent how many months the elephant is from giving birth, in 6 months intervals. Columns 9 and 10 represent the years remaining before an elephant needs to be darted again: column 9 is 1 year and column 10 is 2 years.

The future population is predicted by running the simulation which ages an elephant by 3 years. Using this predicted population the change in the population can be determined by the variable offset which is the target population minus the predicted population. The pregnancies to prevent is given by the offset multiplied by the approximated survivable rate then multiplied by the probability of making it past the first year. The approximated survivable rate is determined by dividing the predicted population by the number of elephants that are of mating age. The desired darted elephant count is equal to the number of undarted female elephants (female elephants - darted elephants) multiplied by their reproductive rate, once every 3.5 years . The old darted elephants is the sum of the values in column 9. The number of newly darted elephants is the difference between the target darted population and the old, still effective population. The expected number of newly darted elephants is equal to the darts fired multiplied by the proportion of undarted elephants per population. By solving for darts fired we are able to determine the darting plan.

Although this model is very effective and implements the occasional twin birth, it would be hard to simplify in order to explain to park management how to dart and when to dart. There were several problems with this model, the first being that it does not keep track of how old the elephants are and the age range for when elephants are reproducing is not clear. Also, it doesn't consider when elephants may need to be relocated or killed in order to manage the population. Furthermore, it does not show what repercussions there are for darting and whether the age structure changes because of it. The main problem is that the model sets a pregnancy term for 42 months when in reality, the gestation period for African elephants is 22 months. Another problem is that the model doesn"t keep track of what happens if a pregnant elephant is darted. Therefore this model would not be reasonable for parks to use.

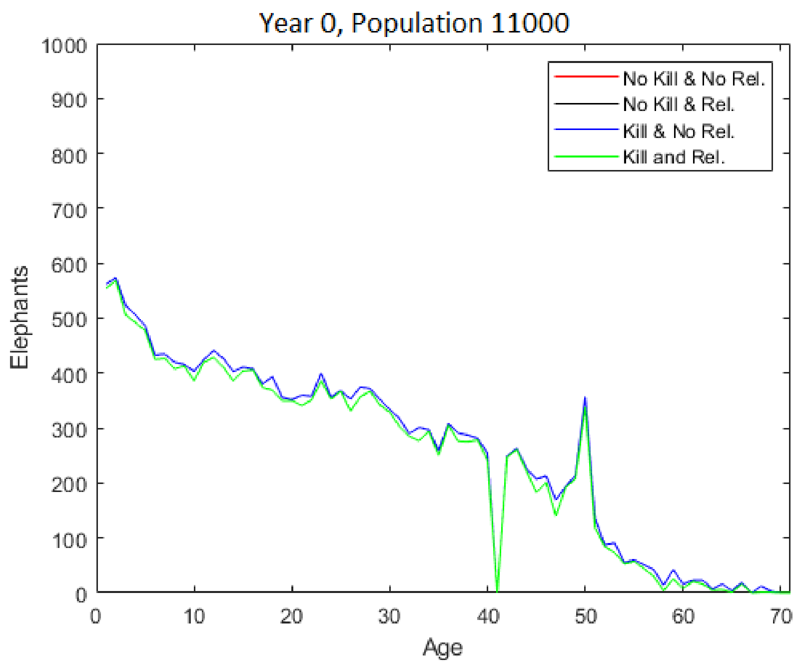
The second approach, the ReLU Darting Model, starts by initializing a random distribution of elephants. Then it initializes how many newborns there will be in year one. This way the model can assign a survival rate to the elephants each year, making the assumption that 100% of the elephants survive from month to month and calculates how many die at the end of each year. When elephants reach age 60 they are eventually killed or die of natural causes, but no elephants survive past 70 years of age. This model is initially set to run for 1,000 years. It records the initial elephant population and which elephants are already pregnant before darting. The model assumes that any elephant can be darted without any negative physiological consequences. There is also the assumption that at 500 years there will be some catastrophic event that will kill around 4,000 elephants. Each year the model assesses the population and determines whether elephants need to be relocated. If they do, then 700 elephants will be removed from the population yearly. The model also checks to make sure that there are not any negative elephant populations and if there are more than the desired number of elephants at the park, including darted, unborn, and undarted. If the population size exceeds the wanted amount of elephants at the park then every elephant between the ages of 9 and 60 is darted. There will also be a random number of elephants that end up pregnant even though they were darted. This model will continue until reaching 1,000 years.

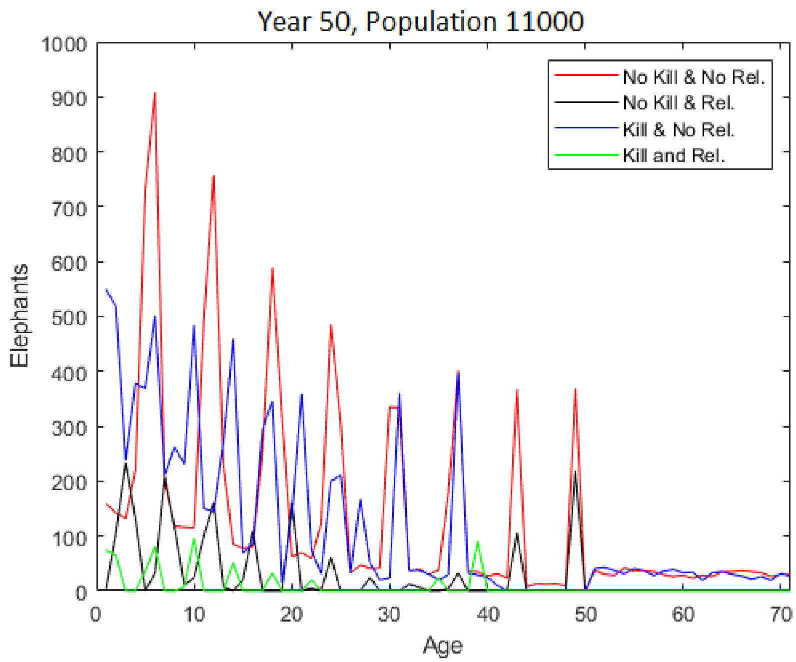
This model has the benefit of being able to continue for a whole millennium. However, it assumes that there is an event that kills thousands of elephants at 500 years. This sort of catastrophic event could happen at any point in time not necessarily just at 500 years. Also accounting for unborn elephants as part of the population isn't reliable because the fetus could die before being delivered or die during delivery, so they can't be considered as part of the population. Another issues is that the model will remove exactly 700 elephants each year if the elephant population is above the desires size, but parks would relocate elephants on financial capability as well as depending on how many are needed to be relocated. In real life, 700 elephants would not be automatically relocated each year to different parks. The other thing that is unclear is if all elephants (including pregnant ones) between the ages of 9 and 60 years get darted or if the model only focuses on elephants that are not pregnant. Although this model would be beneficial to many South African parks, there are events that the model assumes will happen that in real life may or may not happen.

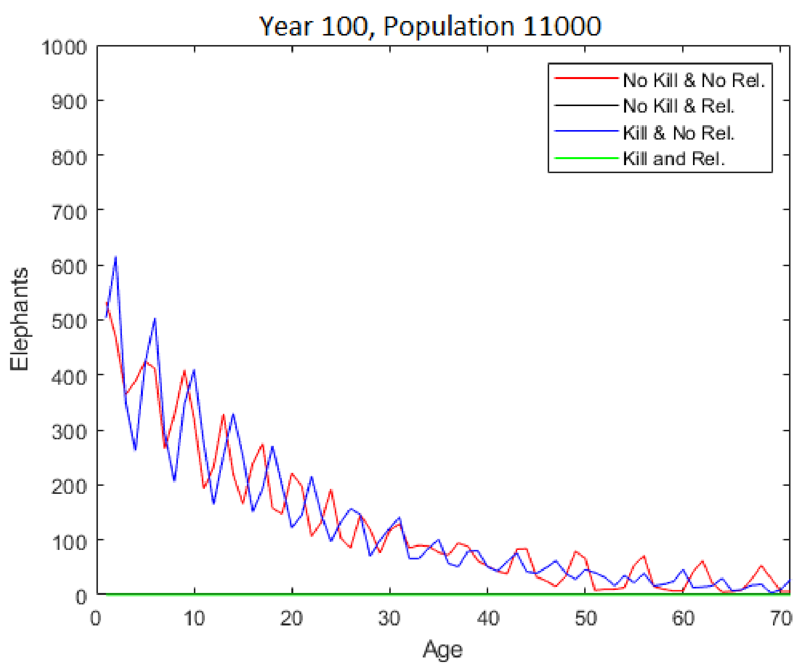
Discussion

The Logistic Darting Model used as a solution to solve the elephant overpopulation problem doesn't account for sudden or drastic losses of elephants. This would depend on the elephants' birthrate. Also, all female elephants between the ages of 10 and 60 years reproduce every 3.5 years. The model can be scaled in order to be utilized for smaller or larger population sizes. The problem of darting along with killing and relocation has a possibility of extinction. This would cause major losses to the tourism industry of South Africa, since elephants are a major attraction in the parks. Furthermore, elephant conservation in Savannah protected areas has net positive economic returns comparable to investments in sectors such as education and infrastructure. Even from a tourism perspective alone, increased elephant conservation is therefore a wise investment by the government of South Africa. Therefore managing elephant population without provoking their possible extinction is beneficial overall to South African parks. The contraceptive dart has been reported from studies to safely and successfully controlled elephant populations. The immunocontraceptive vaccine works by producing antibodies within the elephant to prevent fertilization, without the side effects of hormonal contraceptives . There are numerous reasons why the contraceptive dart is a good solution, including no physiological side effects to elephants regardless of gender or whether their pregnant.

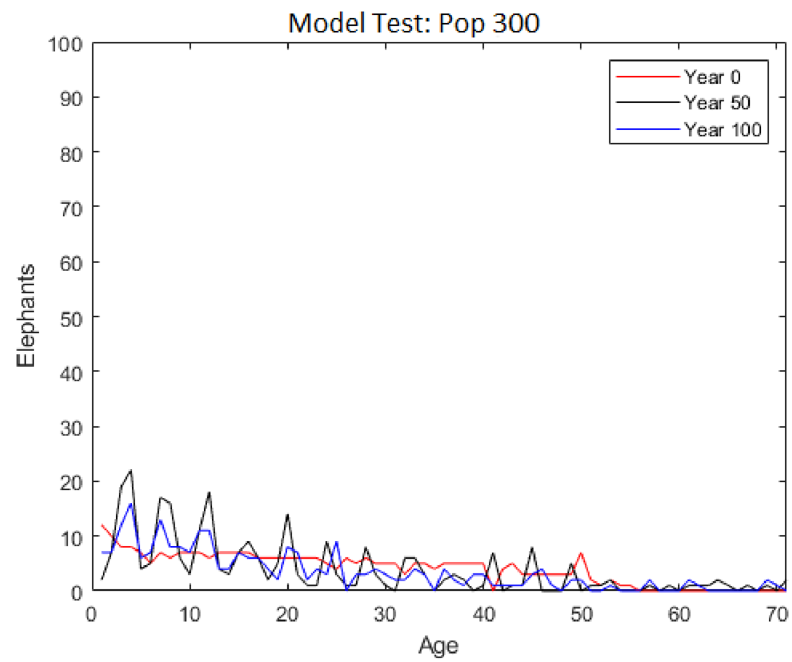
The following plots show how the model progresses in year 0, 50, and 100 with an initial population of 11,000 in accordance to the various options that the model provides.



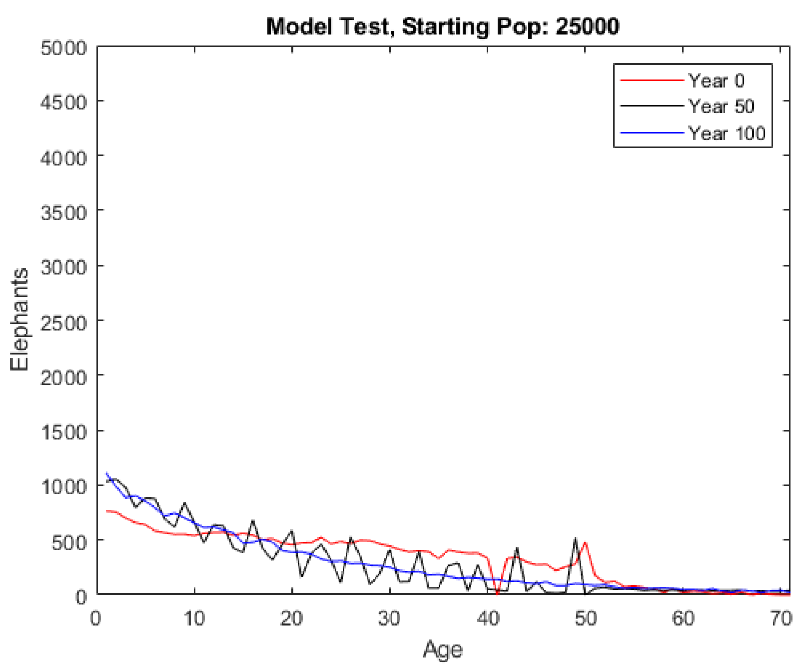




The following plot shows how the model progresses in year 0, 50, and 100 with an initial population of 300.



The following plot shows how the model progresses in year 0, 50, and 100 with an initial population of 25,000.



Conclusion

Overall contraceptive darting is more plausible and effective than killing elephants and relocating elephants in order to maintain the population. Killing the elephants has been controversial, especially because of the profits gained from elephant resources. relocation of elephants seems to be the best method but realistically it comes with problems. Capturing the elephants can be dangerous for humans and elephants, it is also very expensive and reserves lack the financial means,there are only a few areas large enough to receive them and allow for population growth, and the effects of relocation on elephants. There are numerous reasons why the contraceptive dart is a good solution. First, it's incredibly effective. Second, the vaccine has no behavioral side effects. Also if a female who is darted several times will have no side effects and still be protected from conception. Furthermore, there are no effects on already pregnant elephants.

Out of the three approaches the third approach was the most effective. The model utilized probability as a mean of darting and changes the scale of distribution to ensure that the population lies within the desired range. The model considers the effect of darting a pregnant elephant and what it would mean for the age structure. If the pregnancy is terminated the age distribution changes which cause the elephants to age faster. If the pregnancy is carried to term the population will shift to different ages. The model was able to keep track of each elephant and determine their age ,and whether it is pregnant. This models implements darting female elephants each year starting from a population size of 9,000 elephants to manage the elephant population and prevent overpopulating. These are all aspects that would be beneficial to parks in South Africa managing their elephant populations.

Works Cited

Archie, E.A. and Chiyo, P.I. (2012) Elephant behavior and conservation: social relationships, the effects of poaching, and genetic tools for management. Molecular Ecology 21, 765–778

Bertschinger, H.J., Delsink, A., Kirkpatrick, F., Van Altena, J.J., Ahlers, M., Dickerson, T., Powrie, D., and Burger, A. (2013) Porcine Zona Pellucida Immunocontraception of African Elephants (Loxodonta Africana): Beyond the Experimental Stage. Proceedings of the IVth International Wildlife Management Congress: 95-102.

Bradshaw G.A., Schore A N., Brown J.L., Poole J.H. and Moss C.J. (2005). Social trauma: early disruption of attachment can affect the physiology, behavior, and culture of animals and humans over generations. Nature 433, 807.

Breuer, T., Maisels, F. and Fishlock, V. (2016), The consequences of poaching and anthropogenic change for forest elephants. Conservation Biology, 30: 1019–1026.

Butler, Victoria (2011) Elephants: Trimming the Herd. BioScience, Vol. 48, No. 2, pp. 76-81

Fayrer-Hosken, R.A., Grobler, D., Van Altena, J.J., Bertschinger, H.J., Kirkpatrick, J.F. (2012) Immunocontraception of African Elephants NATURE — VOL 407

Garrott, R.A. (2006) Effective Management of Free-Ranging Ungulate Populations Using Contraception. Wildlife Society Bulletin, Vol. 23, No. 3, pp. 445-452

Hanley, N. and Barbier, E. B. Pricing Nature: Cost-Benefit Analysis and Environmental Policy Edward Elgar Publishing (2009).

Keane, A., Jones, J. P. G., Edwards-Jones, G., and Milner-Gulland, E. J. The sleeping policeman: understanding issues of enforcement and compliance in conservation. Anim. Conserv. 11, 75–82 (2008).

Kerley, G., and Shrader, A. (2007) Elephant contraception: silver bullet or a potentially bitter pill? South African Journal of Science, 102, 395–402.

Smith, N., Kerley, G., Page, B., Slotow, R., and van Aarde, R.J. (2006) A scientificperspective on the management of elephants in the Kruger National Park and elsewhere. South African Journal of Science 102

Van Aarde R.J., Jackson T.P. and Ferreira S.M. (2006). Conservation science and elephant management in southern Africa. S. Afr. J. Sci. 102, 385–388.

Wasser, S. et al. Elephants, Ivory, and Trade. Science 327, 1331–1332 (2010).