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The population growth and control of African elephants in Kruger National Park, South Africa:: Modeling, managing, and ethics concerning a threatened species

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THE POPULATION GROWTH AND CONTROL OF AFRICAN ELEPHANTS IN KRUGER NATIONAL PARK, SOUTH AFRICA: MODELING, MANAGEMENT, AND ETHICS CONCERNING A THREATENED SPECIES

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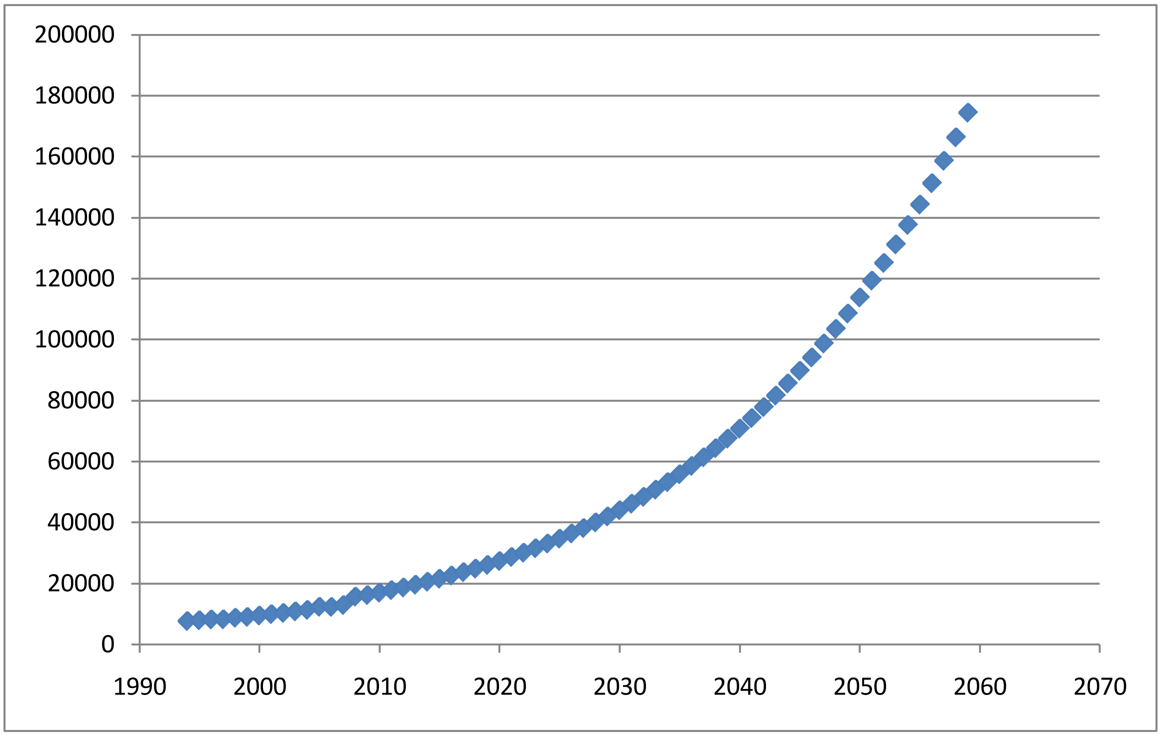

Figure 1: Based on exponential growth, this graph (plotting total elephant numbers against years) projects the effects of density-independent growth on the elephant population of Kruger National Park, South Africa. Exponential growth predicts nearly 1000% growth over a fifty-year period.

Figure 2: Elephant Population vs. Time

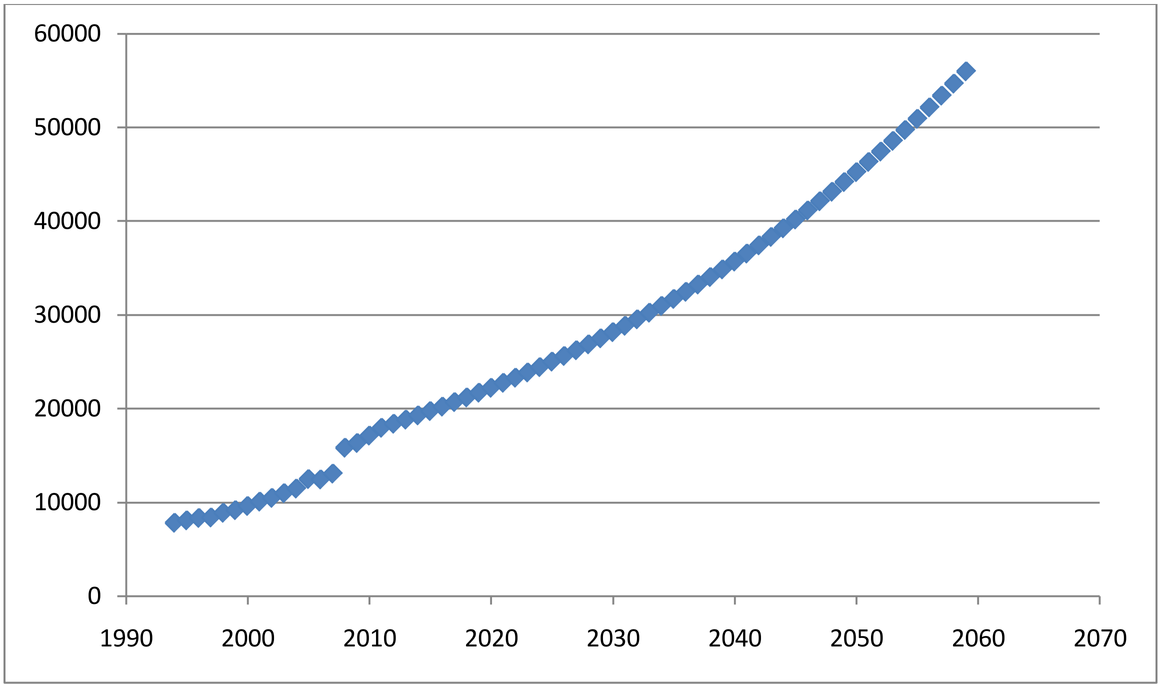

Figure 2: Based on exponential growth and contraceptives, this graph (plotting total elephant numbers against years) projects the effects of density-independent growth on the elephant population of Kruger National Park, South Africa. This model predicts a lower (but still large) growth rate and final population increase of nearly 300%.

Figure 3. Elephant Population vs. Time

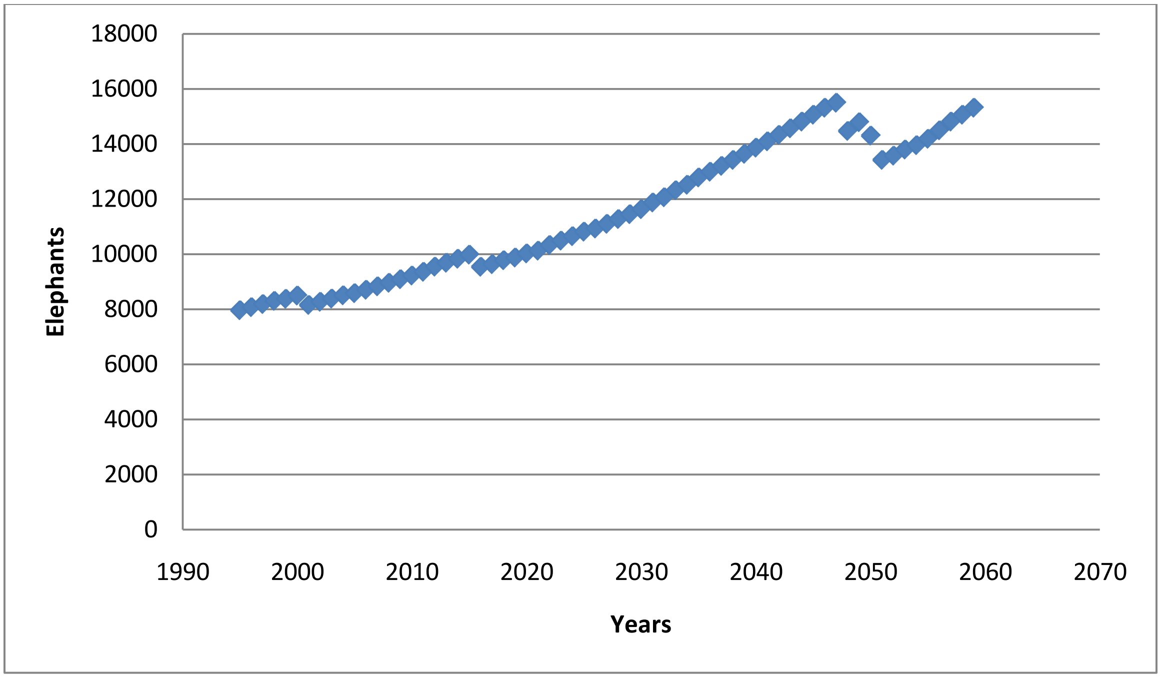

Figure 3: Based on exponential growth, contraceptives, predicted effects from rainfall and small-scale population removal of fifty elephants per annum (culling, translocation, etc.), this graph (plotting total elephant numbers against years) projects the effects of density-independent growth on the elephant population of Kruger National Park, South Africa. This model predicts the lowest long-term positive growth rate of any model run, both those presented in the thesis and those rejected for inaccuracy. This model suggests an approximate 130% growth rate over 50 years.

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Table 1: This table represents the elephant population in Kruger National Park, South Africa from 1994 to 2009 as determined by annual aerial survey. Data was not available for years with blank spaces.

YEAR	E. POP.
1994	7806
1995	8064
1996	8320
1997	8371
1998	8869
1999	9152
2000	
2001	
2002	10459
2003	
2004	11454
2005	12467
2006	12427
2007	13050
2008	15811
2009	16315

Table 2: This table represents the projected growth of the elephant population in Kruger National Park, South Africa if not checked by density-dependence or management actions over the next fifty years. Shaded cells represent the projection. The formula for calculation was: =[previous]*exp(0.0474)

1994	7806	2008	15811	2022	30213	2036	58667	2050	113919
1995	8064	2009	16315	2023	31680	2037	61515	2051	119448
1996	8320	2010	17107	2024	33218	2038	64501	2052	125247
1997	8371	2011	17937	2025	34830	2039	67632	2053	131326
1998	8869	2012	18808	2026	36521	2040	70915	2054	137701
1999	9152	2013	19721	2027	38294	2041	74358	2055	144385
2000	9596	2014	20678	2028	40153	2042	77967	2056	151394
2001	10062	2015	21682	2029	42102	2043	81752	2057	158743
2002	10459	2016	22735	2030	44145	2044	85720	2058	166448
2003	10967	2017	23838	2031	46288	2045	89881	2059	174528
2004	11454	2018	24995	2032	48535	2046	94244		
2005	12467	2019	26209	2033	50891	2047	98819		
2006	12427	2020	27481	2034	53361	2048	103615		
2007	13050	2021	28815	2035	55951	2049	108645		

Table 3: This table represents the projected growth of the elephant population in Kruger National Park, South Africa if checked only by contraception efforts over the next fifty years. Shaded cells represent the projection. The formula for calculation was : =[previous]*exp(0.0234)

1994	7806	2009	16315	2024	24737	2039	35297	2054	50364
1995	8064	2010	17107	2025	25330	2040	36143	2055	51572
1996	8320	2011	17937	2026	25937	2041	37010	2056	52809
1997	8371	2012	18613	2027	26559	2042	37897	2057	54076
1998	8869	2013	19060	2028	27196	2043	38806	2058	55373
1999	9152	2014	19517	2029	27849	2044	39737	2059	56701
2000	9596	2015	19985	2030	28517	2045	40690		
2001	10062	2016	20464	2031	29200	2046	41666		
2002	10459	2017	20955	2032	29901	2047	42665		
2003	10967	2018	21458	2033	30618	2048	43689		
2004	11454	2019	21972	2034	31352	2049	44736		
2005	12467	2020	22499	2035	32104	2050	45809		
2006	12427	2021	23039	2036	32874	2051	46908		
2007	13050	2022	23591	2037	33663	2052	48033		
2008	15811	2023	24157	2038	34470	2053	49185		

Table 4: This table represents a typical instance of the projected growth of the elephant population in Kruger National Park, South Africa if checked by contraception efforts and stochastic rainfall projections over the next fifty years assuming causality between correlations of peak rainfall/NDVI and conception rates. Shaded cells represent the projection. The formula for calculation was : =[previous]*EXP((RANDBETWEEN(1185,2375)*(10^-5))*(1+IF(I59 < 437,-0.5,0)+IF(I59 > 637,0.25,0))+ (IF(RANDBETWEEN(1,13)=1,RANDBETWEEN(-9,-5)*0.01,0))) where the range 0.01185 – 0.02375 represents the projected effectiveness of contraception, the I59 value represents rainfall (generated randomly about the long-term mean), and the final value represents the chance of a seasonal weather fluctuation severe enough to cause drought and increased mortality (between 5 and 9%).

1994	7806	2009	16315	2024	16245	2039	17485	2054	18559
1995	8064	2010	15180	2025	16590	2040	17724	2055	18772
1996	8320	2011	15298	2026	16899	2041	17853	2056	19312
1997	8371	2012	15604	2027	17195	2042	18214	2057	19675
1998	8869	2013	15791	2028	17316	2043	18738	2058	19945
1999	9152	2014	15924	2029	17496	2044	19039	2059	20095
2000	9596	2015	16099	2030	17904	2045	19475		
2001	10018	2016	16418	2031	18322	2046	18409		
2002	10459	2017	16600	2032	17243	2047	17668		
2003	10945	2018	16953	2033	15955	2048	17893		
2004	11454	2019	16007	2034	16072	2049	18162		
2005	12467	2020	16298	2035	16352	2050	18433		
2006	12427	2021	16568	2036	16696	2051	18859		
2007	13050	2022	16952	2037	16913	2052	19269		
2008	15811	2023	16131	2038	17143	2053	18210		

Table 5: This table represents a typical instance of the projected growth of the elephant population in Kruger National Park, South Africa if checked by contraception efforts and stochastic rainfall projections over the next fifty years assuming causality between correlations of peak rainfall/NDVI and conception rates combined with annual culling of 50 animals. Shaded cells represent the projection. The formula for calculation was the same as in Table 4 above, excepting the inclusion of a -50 in the formula.

1994	7806	2010	15786	2026	14866	2042	16067	2058	17031
1995	8064	2011	15793	2027	15100	2043	15440	2059	17085
1996	8320	2012	15906	2028	15145	2044	15711		
1997	8371	2013	16111	2029	15204	2045	15953		
1998	8869	2014	14713	2030	15371	2046	16104		
1999	9152	2015	13849	2031	15506	2047	16186		
2000	9596	2016	14019	2032	14622	2048	16322		
2001	10018	2017	14056	2033	14813	2049	16610		
2002	10459	2018	14198	2034	14851	2050	16718		
2003	10945	2019	14363	2035	14979	2051	16871		
2004	11454	2020	14558	2036	15073	2052	17131		
2005	12467	2021	14785	2037	15309	2053	17420		
2006	12427	2022	14928	2038	15445	2054	17611		
2007	13050	2023	15142	2039	15700	2055	16337		
2008	15811	2024	15206	2040	15915	2056	16724		
2009	16315	2025	15368	2041	15937	2057	16845		

PREFACE AND ACKNOLWEDGEMENTS

Writing this thesis has been a bit like riding a roller-coaster: full of ups, downs, and crazy turns – also, I've never done anything like it until now. What I thought it would be at first has changed radically over the course of the project, and there was work that I did that doesn't really belong in this thesis document at the final curtain. I started this project looking for a genuine mathematical problem that I could address, and found out more about elephants than I ever thought I could.

I'd like to thank first Dr. Trenary, not only for being my thesis advisor, but also for being a great teacher and a real inspiration, and for both expecting my best and accepting my mistakes as learning tools. Without his classes and help, I never would have explored math long enough to develop my passion for it.

I also need to thank Dr. Kleier for being my reader, even though before I walked into her office to pitch this project, we hadn't ever met each other. Her comments and her encouragement have been top-notch, and her help has been invaluable.

My list of acknowledgements would be incomplete without Dr. Bowie, the Honors Director. Over the past four years, Dr. Bowie has encouraged us to search for *magis* and meaning, from the first time I met him to the present day. We tell ourselves stories in order to live, and I have been privileged to have such a wise character in my narrative. I would not have been able to produce this thesis without his advice and guidance.

My family have also been instrumental in my success, and I have to single out my father for allowing me to work long hours – sometimes through the night – at his office, and my fiancée for being so tolerant of the time I've spent ignoring her to focus on completing my work in Honors, including this thesis.

Finally, thank you to my fellow Honors students. Every time I have spoken to high school students visiting Regis and considering Honors, the chief virtue that I extolled was the community, and I would be remiss not to acknowledge the support I have received from my classmates and peers. Thank you for being part of my life for the past four years, and for sharing the burden and pleasure of the Honors program.

INTRODUCTION

Elephants are hard to count. Despite the apparent implausibility of such a statement, it is true (at least in the wild). Although elephants are the world's largest land animals, their size necessitates that they (as a species) are spread out over proportionately large distances, making accurate counts difficult and cost-intensive – many "counts" in parks with large ($n > 50$) populations rely on statistical inferences that may or may not be accurate, based on data collected from aerial surveys conducted from helicopters or fixed-wing aircraft. Despite the difficulty of obtaining information, we have a vested interest in gathering these data about elephant populations because elephants are an endangered species (as of 2012, elephants are classified as "vulnerable" by the IUCN). Furthermore, as international awareness of and interest in conservation increases, so does the widespread sense that people generally and the African societies in direct contact with elephants specifically must act to not only protect the existing population but ensure the ability of the population to grow to a non-endangered threshold. This goal is complicated by the concurrent goal of maintaining biodiversity because of the unique "elephant problem" (Caughley 1976): There are not enough elephants in the world (in the sense that most conservationists and biologists believe that to guarantee the future of African elephants, there is a minimum necessary population threshold), and yet where elephants exist – indeed, thrive – there are too many of them. That is to say that many elephant populations in wildlife preserves currently are near or exceed the density at which elephant drastically change their landscapes through grazing, debarking of trees, and other ecological impacts (Kerley, 2008; van Aarde, 2008). This landscape-scale impact often negatively impacts biodiversity by extirpating or threatening the extirpation (local extinction) of preferred species of tree or aloe (Kerley, 2008). In order to accomplish both conservation goals, it becomes useful to understand elephant population variations, trends, and the factors which affect them. Towards that end, I am developing a mathematical model to explain and predict population variations and outcomes. Part of evaluating the management decisions involves not only choosing actions which bring about acceptable consequences in the ecosystem, but are also in and of themselves acceptable actions to the concerned parties (for example, increasing the land available to wildlife preserves by demolishing or preventing the construction of buildings or farms might be beneficial to the elephant population but not be acceptable to the general public). Therefore, part of assessing the model and the management decisions and their outcomes must be to consider not only the numerical impacts but also the social ramifications for elephants and the ethical issues surrounding management.

In this thesis I will discuss an approach to modeling and several possible applicable models, as well as discussing one particular model that describes and projects the population changes and constraints in Kruger National Park, South Africa. This model will include several different management options, with preference placed on projected effectiveness of implementation and ethical considerations. The ultimate goal of the modeling process is to obtain a mathematical representation of the elephant population which can accurately predict the growth or decline of elephant populations for the purpose of maintaining biodiversity.

ECOLOGICAL BACKGROUND

The African elephant (*Loxodonta africana*) is the largest land animal on the planet. An herbivore, the African savannah elephant is separate species from its cousins the Asian elephant and the forest elephant (*Loxodonta cyclotis*), which is also native to Africa. Although there is strong genetic evidence that the two species are distinct, for conservation purposes the IUCN has as recently as 2007 classified *Loxodonta africana* and *Loxodonta cylcotis* as the same species (Carruthers 2008). Elephants are what's known as megaherbivores, meaning herbivores which on average weigh more than 1,000 kg. Elephants are not picky eaters; they are both browsers and grazers (Owen-Smith 2006). There are approximately between 500,000 and 700,000 African elephants in the wild as of the 2007 African Elephant Status Report released by the International Union for Conservation of Nature (Blanc 2007). These elephants have no natural predators as adults, although predators like lions will attack juvenile elephants given the opportunity (Loveridge 2006). Rather than being in danger of extinction or extirpation in most areas, then, the African elephant population is on the whole increasing (Blanc 2007), and this is particularly true in southern Africa (Carruthers 2008).

Human intervention is the most important factor to a sustainable elephant population in the wild. Of the four main issues affecting African elephant conservation as identified in the African Elephant Status Report by the World Conservation Union, three were directly caused by humans, and the fourth indirectly: habitat loss/fragmentation, human-elephant conflict, poaching or hunting and negative localized environmental impacts, respectively (Blanc 2007). Although hunting and poaching gained notoriety for decimating elephant populations in the nineteenth and late twentieth centuries, it is not currently a major factor in elephant population dynamics because of increased international regulation of the ivory trade and increased policing in African states (Twine 2008). Habitat loss and fragmentation is instead the most immediate problem, along with its consequence of negative localized impacts (Kerley 2008; Shrader 2010). Although there are dozens of established parks in Africa both public and private, there are increasingly few areas available to be turned into parkland. This means that elephant populations are often physically separated and unable to expand beyond the boundaries of their parks, particularly when the conservation areas in question are fenced (van Aarde 2008). From the perspective of genetic diversity, this means that either conservationists must transfer individuals between parks for breeding to ensure genetic diversity or larger spaces for parks must be obtained.

Because of the enclosed nature of the wildlife preserves in which elephants reside, their populations are necessarily bounded by the resources inside the preserves. As adult elephants have no natural predators and hunting/poaching has been largely eliminated, the size of any given population is limited primarily by the amount of available food and water; these resources are also consumed by the other animals in the park. This makes predicting the growth of elephant populations a complicated process.

THE MODELING PROCESS

Mathematical modeling is the process of describing a real-world situation with a mathematical equation. Modeling almost always involves a simplification of the processes at hand in order to produce a model which is workable at the expense of some realism. A model is generally considered valid if it accurately describes the system in question. There are several stages to building a successful model. One of my two primary sources of modeling theory suggests the following eight stages: establishment of goals/objectives, identification of system features/boundaries, development of the mathematical/simulation model, sensitivity analysis, verification, validation, stability analysis and finally application (Williams 2002). As many of these as possible are included in the model presented later/

The first stage (establishment of goals/objectives) can be relatively straightforward. There are five possible goals of building a model (all of which are to some extent mutually exclusive): generality, realism, accuracy, identification of information deficiency, and management decisions (Williams 2002). General population models are designed to be broadly applicable across many species/environments. Such models are evaluated based on their ability to highlight general patterns in population shifts, and are characterized by model simplicity, a lack of biological detail, and low precision when representing particular biological systems (Williams 2002). Population models designed to be highly realistic focus on biological mechanisms and thus incorporate highly detailed descriptions of biological processes, with precise mathematical terms describing them. The level of detail limits the generality of the model and may cause imprecision when estimating model parameters. Furthermore, the precision of terms in the model may cause erroneous assumptions about the validity of the model to a layperson (Williams 2002). Model accuracy is particularly important for predictive models, i.e. models that seek to predict population changes under varying conditions. Predictability is often obtained by limiting the scope of the model, to the detriment of realism and generality (Williams 2002). Sometimes, the goal of the modeler is to explore the adequacy of the available data and identify the lacking information which must be provided to further understanding of a problem or system. Models developed for this purpose often are broadly conceptual and sometimes consist of graphical/logical representations of biological interactions (Williams 2002). These models attempt to forecast the biological impacts of management decisions, accounting for both population effects and management costs/benefits. A distinguishing characteristic is that these models include decision variables which influence population dynamics (Williams 2002). Of these five goals, the one on which this thesis focuses is the fifth, management decisions.

The second stage of Williams' approach to modeling is identifying the system features and boundaries. Some of the primary concerns when building a model are the selection of what is to be included and what is to be excluded (Williams 2002).In the case of this thesis, the system will be Kruger National Park, South Africa. The features and boundaries will be representative of the park as far as possible, including rainfall, NDVI, age structure, and existing population size.

The third stage is development of the mathematical/simulation model. In the case of this thesis, several potential models will be discussed before one is selected. Essentially, the development of the mathematical model rests on seven things to include: accumulators, sources, sinks, flow, flow regulators, exogenous variables and artificial controls (Williams 2002). Accumulators include elephant population, net primary production of plants (NDVI), water resources, and other resource/population aggregations. A source represents an input to the system from without, like precipitation into a water accumulator, whereas a sink represents an output of the system to the external, i.e. population loss from death or fire. Flow is the internal, directional movement of material between accumulators, in which one accumulator is depleted and one is increased, as in birth, death, migration, and transfer of individuals between parks. Flow regulators (unsurprisingly) regulate the rate at which flows occur, and may represent birth rate, death rate, etc. Exogenous variables are factors that influence the movement of material across system boundaries, influencing but not being influenced by the dynamics of the system, and include sources and sinks (as well as other nonmaterial information transfers). Controls represent management decisions (adding/removing artificial water supplies, for example).

Some existing models will now be presented, and their parameters, advantages, and disadvantages mentioned.

- Exponential Growth Model

- $P(t) = P_0e^{kt}$
    - P_0 is the initial population
    - k is the growth/decay rate
    - t represents time
- Advantage:
    - Simple, easy to compute
- Disadvantage:
    - Grossly inaccurate over long periods of time for most (non-microbial) populations

- The Logistic Model
    - $dP/dt = rP(1 – P/K)$
        - P is population size
        - K is the environmental carrying capacity
        - r defines the growth rate
    - Advantage:
        - Incorporates a regulatory constraint imposed by the environment
    - Disadvantage:
        - Generality inhibits precision
- Cohort Model
    - Rather than a particular mathematical expression to describe the population, this is a conceptual approach useful when the population in question is divided into distinct categories (Ex: populations on distinct

game reserves are modeled individually) The model combines the distinct population models into a metapopulation model. The cohort approach can be generalized to age structures, genders, etc.

- Lotka-Volterra Predator-Prey Model
    - System of differential equations:
        - $dx/dt = (a - by)x$
        - $dy/dt = (-m + nx)y$
            - Where $a – by$ is the intrinsic growth rate of the prey and $–m + nx$ is the intrinsic growth rate of the predator population, $a,b,m,n > 0$ and determined by the data available
    - Advantages:
        - The system is self-regulating and capable of equilibrium
        - The system is easily modified to account for competition instead of predation and can be manipulated to account for density-dependence
    - Disadvantages:
        - The model only accounts for two species without regard to outside factors

After examining the data and attempting to fit several variations on these models to the existing population data, the model which best fits the data collected in Kruger since elephant culling ceased in 1994 is the exponential growth model, suggesting that there are few (if any) natural braking effects on the growth rate of the population in Kruger at this time. The next section will discuss in more detail the constructed model.

BUILDING THE MODEL

Some preliminary testing suggests that the following are the essential elements to modeling the “natural” growth of an elephant population, as well as the effects of the management decisions that can be applied to the population in order to affect the population’s size or growth rate: Rainfall/water and food availability, current/recent population size/density, and age structure (which influences breeding and death rates) are essential elements, while culling, contraception, translocation and property expansion are potential management tools. These are described below.

The first element that will be included is rainfall/water availability: elephants are “water-dependent” (Kerley 2008); adult elephants drink approximately 225 liters (or 60 gallons) per day (Blanc 2007); and there is strong evidence that rainfall influences conception rates (Gough and Kerley 2006). Published studies suggest that most elephants drink every 1-2 days (Owen-Smith 2007) or, in drier climates, at intervals of at most 5 days (Viljoen 1988). Therefore, droughts increase elephant mortality significantly, particularly among juvenile elephants younger than twelve (Dudley et al., 2001). This is not only because the juveniles die of dehydration, but also because the probability of predation rises significantly (Loveridge 2006). Although grown elephants have only one natural predator (*Homo sapiens*), lions will attack juvenile elephants which are undefended by adults. For a variety of reasons, juvenile elephant mortality attributable to lion predation rises during extended periods of drought (Loveridge 2006).

Current and recent population size and density are also important: The larger an elephant population that is unconstrained by management actions or carrying capacity is, the higher the growth rate – however, there is evidence to suggest that birth rates (and therefore growth rates) rise when density is artificially lowered, as by culling (van Aarde 2008). There is evidence that the converse is true, and growth rates slow naturally when densities are high (van Aarde et al 1999) but the population density at which growth rates slow is dependent on several factors, including resource availability, and the relationship is not well studied (van Aarde 2008).

Age structure is both important and difficult to determine because of the relatively long lifespan of the African elephant. Although studies of elephant longevity are uncertain, there is a general consensus that the average age to which an elephant might live is approximately 60 (Blanc 2007). However, the probabilities that elephants will reach this age are low, particularly given that poachers tend to target elephants with the largest tusks because tusk growth is proportional to age (Sukumar et al. 1988) This means that poachers tend to target the most experienced elephants in a herd, thereby reducing the average age by eliminating the oldest elephants. This is significant because McComb et al (2001) show that families with older matriarchs have greater reproductive success, which may be attributable to greater experience and more nuanced communication ability (McComb 2001), and therefore the model should incorporate higher growth rates corresponding to family groups with matriarchs older than some threshold, approximately

40-45. However, studies have determined that elephants 15-25 years old contribute the most to population growth (van Aarde 2008), and also that manipulating the proportion of juveniles to adults in a population through culling is the most effective way to stabilize population growth with culling (Woolley 2008).

MANAGEMENT DECISION OPTIONS

The most historically used (and most controversial) management option is culling, which consists of killing elephants and may be applied for various reasons. Culling to reduce population (almost universally for the purpose of reducing undesirable effects of high elephant densities) is only effective in the short term, as reducing density may lead to optimal population growth rates (Caughley 1983; van Aarde 2008), unless culling is done selectively by age category (Woolley 2008; Slotow 2008). Furthermore, culling to reduce population is an unpopular management choice among many of the “stakeholders” in the continued existence of elephants, animal rights groups being some of the most vocal and easily recognizable. Culling as an intervention in cases of “rogue” elephants – elephants which are excessively aggressive towards humans or other endangered species – is philosophically distinct from culling to control population, and is in common use when elephants pose immediate threats to people or human livelihoods, as may occur when elephants escape from fenced-in conservation areas and threaten crops, or when an elephant which has witnessed poaching or culling becomes aggressive towards humans, to give two examples (For this reason, current best practice is to cull entire herds at once (Slotow 2008). Culling to destroy aggressive animals does not have a significant effect on elephant population dynamics (Slotow 2008).

One of the newest management options is also the least tested during long periods of time: contraception. As a management tool, contraception is relatively new: the first elephant contraceptive was developed in 1989 for other species and first tested on elephants in the wild in 1996 (Bertschinger 2008). Therefore, the long-term physical and social effects of applying contraceptives to elephants are unknown; however, in the short term, contraception is effective. In a study by Mackey et al (2009), contraception of 75% of the female elephant population led to a reduction in population growth rates of approximately 64% (Mackey 2009). The most common contraceptive in use is PZP (porcine zona pellucida vaccine), which is preferred over other methods of contraception like castration for reasons of cost on a large scale and behavioral changes caused by gonadectomies (Bertschinger 2008). Some potential effects (as identified by Kerley and Shrader 2007) include increased risk of physical harm to contracepted females due to a fourfold increase in the frequency of estrous and consequently increased incidences of sexual attention from bulls, although as Bertschinger points out, this is a controversial assertion (Bertschinger 2008), as well as potentially increased “male-male aggression over mating opportunities” (Kerley 2007), fundamental changes in herd dynamics due to a decreased ratio of adult females to calves, and the potential negative impact on the practice of “allomothering”, the process by which young female elephants serve a kind of “motherhood apprenticeship” (Lötter 2008). As every article on contraception notes, these potential long-term effects may or may not occur, and further research is needed.

Translocation, another management option, is the removal of elephants from one place to another. This diminishes local elephant densities on a similar scale to culling, but does not involve the killing of elephants. It may also be undertaken in order to either introduce elephants to a game reserve – often done because the presence of elephants in a game preserve increases eco-tourism (Grobler 2008) – or to introduce genetic diversity to a population (Grobler 2008). Translocation therefore has the benefit that the overall population is not diminished. However, translocation of elephants to reduce local density effects has the same effect as culling in that it creates optimal reproductive conditions, tending to raise the birthrate and therefore nature compensates for the affected densities. Furthermore, as a method to curb negative elephant density effects, translocation is a temporary solution at best. The primary factor limiting translocation as a tool for population management in light of density effects is the absence of available land to which elephants may be transported (Grobler 2008); the secondary factor is cost: technological and innovative advances have been made so that it is not a technical challenge to translocate any number of elephants over any distance (Grobler 2008). For social reasons, entire family groups are translocated together.

A fourth management option is water provision/deprivation. This management option was developed both because elephants are highly water-dependent and because many conservation areas are naturally dry (Chamaillé-Jammes 2007); however, the effects of providing or removing artificial waterholes on elephant populations or the plant life in surrounding areas are not yet well understood (Kerley 2008).

Finally, one last management option is property expansion: One of the most effective and least feasible management tools, property expansion is simply adding area to existing wildlife preserves. This is an ideal solution insofar as adding area viable for elephant populations has the potential to reduce density effects on the local scale while allowing for a larger total elephant population. This is an impossible solution insofar as the land which might be annexed is virtually all in use for agricultural, industrial, or otherwise cultural pursuits. Autocratically displacing the people whose livelihoods are tied up in this land is ethically dubious at best, and funds to buy land are often finite and low to nonexistent. Therefore property expansion is ideal from a management perspective and impractical from an economic perspective. This is why private game reserves are useful for the conservation of elephants.

SHAPING THE MODEL

We start with a simple expression of exponential growth, where the rate of growth is fitted to an existing data set using Microsoft Excel and time is measured discretely in years. Using this software and the Kruger National Park elephant population data from the last eighteen years (Table 1), an average rate of 4.74 percent growth per annum was extrapolated. Using this figure and the assumption of density-independent growth, a first crude population projection was established for the next fifty years (Figure 1, Table 2), which suggests that the elephant population will increase tenfold over the timespan of the model – less than the natural lifespan of an elephant. Although this is a highly unlikely figure, it is not known at what density elephant populations experience density-dependent effects (Woolley 2008), and so we let the assumption stand in order to investigate the consequences of management decisions, which will act as artificial density-dependent parameters. Our model begins like this:

Next, using data extrapolated from Grobler (2008) and Mackey (2009), we assume contraception of 80% of the female population will produce a reduction in the growth rate of 50% (Figure 2, Table 3) which implies the population will still quadruple within fifty years.

We then refine the model further by taking into account a combined factor of rainfall and NDVI, which are positively correlated with conception rates (Gough and Kerley, 2006) by increasing the population growth rate by 125% two years annual rainfall is more than (approximately) one standard deviation from the annual mean and decreasing the population growth rate by 75% when annual rainfall is less than one standard deviation from the annual mean. NDVI was assumed to be proportional to rainfall and did not act as an independent variable.

R: Rainfall measured in mm/year

Rainfall was determined stochastically based on available data and long-term averages for Kruger National Park, assuming a normal distribution and periodic drought episodes resulting in mortality rates of 5-9% every 13-16 years, based on studies of density dependence and drought mortality (Dudley et al., 2001 and Woolley 2008). The resulting population growth projection predicts doubling the population inside fifty years (Table 4, Figure 3). Adding either annual culling of 100 juvenile females or annual translocation of the same to the model both increases the stability of the model (the range of the projected population after 50 years is decreased by 18%) and results in an average growth rate of less than half a percent, resulting in steady but slow growth and an increase in the population of 130% over the next fifty years (Table 5, Figure 4), which allows for incremental increases in density and therefore ideal conditions for biological conservation.

d: Probability of a drought that causes between 5-9% mortality

This is the most effective model within the parameters of the data extrapolated from the literature because it achieves the biodiversity goals of conservation managers seeking to balance elephant populations with the changes high elephant densities make to their environments. However, this model is not ideal. The data necessary to better define some of the relationships in the model is in some cases unpublished (particularly extensive historical rainfall records or the precise age structure of the elephant population in Kruger National Park) or even uncollected (as is the case with the long-term effects of contraception). Therefore, many of flow regulators in the model are not necessarily accurate, although they are based on published information available from peer-reviewed journals and park data when available. Although this uncertainty exists, it should be noted that the model agrees with the vast majority of literature in emphasizing the effects of contraception, drought-related mortality and age-based culling (real or simulated by translocation) as the most effective ways to limit population growth, and that the model fits the available data.

ETHICAL CONSIDERATIONS

The management decisions that are the most effective may not necessarily be the most ethical ones; this next section will explore the ethical discussions surrounding various kinds of management, in order from most contentious to least contentious topic: Culling, contraception, and land acquisition/park creation.

Culling, or killing elephants, is by far the most ethically contentious management decision. The advocates of culling often approach the issue from an ecosystem-oriented value perspective, whereas the opponents of culling most often approach the issue from a perspective that values animal rights. As mentioned above, the model benefits both in stability and overall growth rate from the inclusion of culling as a management technique, so it is particularly relevant to bear in mind.

Opponents of culling most often object of grounds of cruelty and animal rights. As an ethical issue, let us first examine animal rights. Many intellectual approaches to animal rights have links to the work of Peter Singer, who makes the claim that humans do not deserve any more or any less than any other member of the natural world, and therefore have no business claiming ethical superiority over other creatures (Singer, 1985). He justifies his anti-exceptionalist attitude by counting all animals as morally relevant by virtue of their ability to experience pain or distress and also pleasure (Singer 1985). However, Singer acknowledges that, as humans have more complex and intricate experiences of these things than do other animals, killing a human can be worse than killing a snake (Singer 1985) which is essentially a utilitarian approach. This approach could justify culling if the number of elephants had enough of a negative impact of the other members of the ecosystem; however, there is not enough information on elephant impact on surrounding species to determine an appropriate metric with the specificity one would like (Lötter 2008). After Singer, Tom Regan developed a theory of animal rights in which was the most prominent theory explicitly valuing individuals over populations (Lötter 2008).

Regan's view (or a variation thereof) is the one most commonly held among opponents of culling today. Although Regan draws on some of Singer, he rejects the utilitarian conclusions in favor of the opinion that killing individual animals is unacceptable independent of the outcomes for the other members of the ecosystem (Lötter 2008), and generally favors a laissez-faire attitude towards human intervention in the affairs of nature.

Beyond appealing to theories of animal rights, opponents of culling also cite studies and observations which demonstrate that elephants are, along with dolphins and primates, some of the most "intelligent" species alive. Physiologically, the volume of an elephant's brain is comparable (proportionally) in size and complexity to humans (van Aarde). Elephants are highly social creatures with well-defined social structures (Gough and Kerley, 2006). They also exhibit curiosity, playfulness, and apparently grieve for their dead by exhibiting behavior such as trying to lift recently dead elephants onto their feet, identifying and examining the carcasses of dead elephants both within and without family groups, and similar behavior (Douglas-Hamilton et al., 2006). It is this last feature that critics of culling emphasize the most, along with studies that suggest culling has a negative effect on the behavior of nearby elephants (Lötter, 2008). Although the attribution of "intelligence" to elephants based on these behaviors is projection and inference, there is a strong emotional argument to be made.

In favor of culling, there is the argument that in spite of some apparent social similarities between humans and elephants, the most significant difference between elephants and humans is that elephants cannot reason abstractly, and cannot explain or understand the effects of their behaviors on their surrounding ecosystem (Lötter, 2008). Furthermore, Regan's argument is problematic insofar as animals (including elephants) do not have the same accountability of action (or, in other words, agency) that people do. As Lötter notes, not only do humans have the greatest agency of all animals, but humans have also already interfered with nature, and must take responsibility for it, interfering to conserve the most natural state which can be achieved (Lötter 2008). This is the view taken by many ecosystem-oriented ethical positions, including the IUCN, WWF and South African National Parks (SANParks). This position implies a holistic approach to conservation, in which "all aspects of conservation areas should be protected so as to allow and enable nature to function, as far as possible, on its own without human interference or even without benevolent human intervention" (Lötter 2008). Despite the injunction against interference, this approach tends to favor the use of human intervention in order to maintain the overall health of the ecosystem.

Another perspective is that of traditional African approaches to elephants, which can be summarized as respectful, sustainable use (Lötter, 2008). Although there is not a single, unambiguous interpretation of traditional African use of natural resources including elephants, there is general consensus that it involves sustainable consumption (Lötter, 2008). This perspective would support the sustainable killing of elephants for commercial gain, whether that would take the form of hunting for food, culling and selling ivory for the benefit of local people, or selling hunting licenses (Schmidtz, 1997; Lötter 2008). Although this does not directly address the issue of culling from a management perspective, it does inform various alternatives to culling that serve the same purpose (i.e. total reduction in numbers).

Contraception, while less contentious than culling, relies on many of the same interference/non-interference arguments made above. Particular to this issue are the unknowns related to contraception's long-term effects on individual elephants and herd dynamics. Proponents view contraception as an effective and non-lethal management tool with few downsides, whereas opponents tend object to interference generally, cost, or potential future effects (Bertschinger, 2008). In particular, many researchers have suggested that large-scale contraception necessary to reduce growth rates would also reduce the number of newborn calves in a herd to the point where the formative practice of allomothering would be severely affected (Bertschinger 2008). As a "motherhood apprenticeship", allomothering gives young female elephants the opportunity to learn how to raise calves in the social setting of the herd (Kerley, 2007; Bertschinger, 2008). Opponents' objections to high contraception rates primarily center around the possibility that reduced numbers of calves would lead to a decline in the opportunities for allomothering or an increase in the size of family groups in order to maintain allomothering, both of which run counter to the philosophy of non-interference (Lötter, 2008) suggested by animal-rights activists.

On the surface, land acquisition/park creation is an ideal solution to the problem of high elephant densities; however, ethical issues arise regarding the treatment of citizens who may be either forced off of the land they live on or forced to change their way of life in order to adapt to park creation. Elsie Cloete notes that the traditional way to establish a conservation area is to either evict entirely or conditionally accommodate humans previously occupying the new conservation space (Cloete, 2008). In the context of Cloete’s article, conditionally accommodate means to essentially prevent subsistence farmers from continuing with their way of life by preventing farmers from using more deterrents than loud noises to drive away elephants, who can eat or trample an entire year’s worth of crops within a single day. Therefore increasing the land available to conservation areas displaces indigenous populations either physically or occupationally (Cloete 2008).

CONCLUSION

There is a clear need for conservation programs to manage not only elephants but their ecosystems as well. This management should be guided by science and ethical discussion working in tandem. In this thesis, I presented a model that suggests a managerial course of action informed by projected population growth linked to population density. This model suggests widespread contraception and small-scale culling efforts. When ethics are included, this prescription is modified somewhat to suggest that of the killing of elephants that should occur, it should be done in such a way that the community benefits (i.e. the elephants should be processed for meat and tusks, and the proceeds used for local charities or other community-based and locally-designated sources) and also so that the elephants experience a minimum of suffering.

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