POPULATION AND HABITAT VIABILITY ASSESSMENT FOR THE NAMIBIAN CHEETAH *(Acinonyx jubatus)* AND LION *(Panthera leo)*

11-16 February 1996
Otjiwarongo, Namibia

Workshop Report
February 1997

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Compiled by the Workshop Participants

A Collaborative Workshop

Namibian Ministry of Environment and Tourism
Cheetah Conservation Fund
AZA Felid Taxon Advisory Group
AZA Cheetah Species Survival Plan
AZA Lion Species Survival Plan
IUCN/SSC Cat Specialist Group
IUCN/SSC Conservation Breeding Specialist Group

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Table of Contents

PHVA Workshop for the Namibian Cheetah and Lion

Executive Summary

Section 1. Introduction and Overview

Section 2. Working Group Reports - Cheetah

Section 3. Working Group Reports - Lion

Section 4. Appendices

Executive Summary

PHVA Workshop for the Namibian Cheetah and Lion

Originally, cheetah *(Acinonyx jubatus)* were found from the Cape of Good Hope to the Mediterranean, throughout the Arabian Peninsula to the southern part of the former Soviet Union. Population numbers have declined from more than 100,000 in 1900 to approximately 9,000 to 12,000 free-ranging cheetah in Africa. Two population strongholds remain: Kenya/Tanzania in East Africa and Namibia/Botswana in southern Africa. In Namibia, between 1980 and 1991, the population of cheetah was estimated to have declined by 50%, leaving a population of 2,500 animals. The decreasing numbers are a result of drought, human, livestock and predator conflict. As humans turn more and more of the cheetah's habitat into farmland for livestock production, cheetah are routinely indiscriminately killed as being possible livestock predators.

Namibia also is home to a unique and significant lion *(Panthera leo)* population which is seriously threatened by drought, human conflicts, range loss and potential disease threats. Historically, lion ranged over most of the northern half of the country and partly in the east, west, and south. Few historical quantitative population estimates are available, though total lion numbers were estimated at 500 in 1975 and 700 individuals in 1980. Since then, the lion population in Namibia has been declining and is now estimated at 300 animals. This trend represents up to a 50% decline in lion numbers over the past 15 years. About 85% of the lion in Namibia currently are restricted to two protected areas: the Etosha National Park (160 to 180 lion) and Kaudom Game Reserve (50 lion).

To address these and other problems, a PHVA Workshop for the Namibian cheetah and lion was held from 11-16 February 1996 in Otjiwarongo, Namibia. The workshop was a collaborative endeavor of the Namibian Ministry of Environment and Tourism, the Cheetah Conservation Fund, the AZA Felid Taxon Advisory Group, the AZA Cheetah and Lion Species Survival Plans, and the Conservation Breeding Specialist Group of the IUCN-World Conservation Union's Species Survival Commission. The meeting was hosted by the Cheetah Conservation Fund and generously sponsored by British Airways, White Oak Conservation Center, Columbus Zoo, NOAHS Center-Smithsonian Institution, Philadelphia Zoo, Fort Worth Zoo, Zoo Atlanta, Oklahoma City Zoo, Rio Grande Zoo, Houston Zoo, Caldwell Zoo, Franklin Park Zoo, Binder Park Zoo, and the Nashville Zoo.

Participants were welcomed and the meeting was officially opened by His Excellency Dr. Sam Nujoma, President of the Republic of Namibia. Mr. Kavetuna, Mayor of Otjiwarongo, and Mr. Marshall McCallie, the U.S. Ambassador to Namibia, also welcomed the participants, followed by a welcoming presentation by Mr. Gert Hanekom, the Namibian Minister of Environment and Tourism (MET).

The first day's activities were attended by more than 100 participants from 10 countries, represented by stakeholders in the future of the two species: MET officials, farmers, conservationists, and scientists. Overview presentations concerning the status of both the cheetah and lion and the goals of the workshop process set the stage for the weeklong activities. The first afternoon was designed to address farmers' concerns; most farmers could not attend the workshop after the first day because of personal commitments to caring for their livestock. They expressed their primary dilemma as wanting to know how to maintain commercial livestock farms without being forced to kill cheetah and lion in order to protect their livelihoods.

Participants were divided into seven homogeneous stakeholder groups: farmers with lion problems, ministry personnel, farmers with cheetah problems, and two groups each of conservationists and scientists. Each group was asked to list three to five of their most urgent problems relating to the species, with instructions to state them using consensually-reached, issue-based statements (e.g., "The critical problems for us are . . ."). The second portion of the small group task centered on generating a discussion of needs, with each group asked to explicitly state their own needs, followed by a "why" statement. For example, rather than saying "We need more open communication" or "We need to retrieve carcasses of dead lion and cheetah", participants were asked to use statements such as "We need more open communication in order to understand in what way Ministry policies or initiatives help protect these species" or "We need to retrieve carcasses of dead lion/cheetah in order to analyze threats, such as disease, to our populations".

Each group presented a brief synopsis of its results. A group of four participants then presented commonalities and differences among the problems and needs expressed by each stakeholder group. Common themes clearly emerged:

1. Communication/education/cooperation
2. Basic research, including: identifying critical threats; long-term monitoring to detect population trends; range, habitat, and prey to ensure viable populations; and global management of captive populations;
3. Funding to implement 1. and 2.;
4. Economic considerations including impact, asset value of lion and cheetah, integrated wildlife and livestock management (land-use), restricting range of lion and cheetah, practical solutions to the needs of people, and evaluation of appropriate sustainable land-use systems.

The following 4 days of the PHVAs for the two species focused primarily on distribution, status and threats to those species and existing and proposed management strategies. Six working groups were developed (Wild Management Goals and Strategies, Human/Livestock Interaction and Communication, Life History/VORTEX Modeling, Disease, Genetics and Captive Populations); each group was comprised of international as well as Namibian participants. The tasks of the working groups for the next 4 days then were to:

1. Identify the main issues and problems.
2. Determine goals in terms of identified issues and problems.
3. Develop promising strategies and solutions to address (1) and (2) in light of available data, and then prioritize in light of the needs expressed by the various stakeholder groups.
4. Turn the highest priority strategy into realistic action steps in terms of particular time frames and when possible to identify available and potentially available resources.
5. Report daily (orally) on discussions to receive input from other participants.

The **Wild Management Goals and Strategies for Cheetah** working group determined that the greatest problems for cheetah are the general population decline, as well as killing of significant numbers annually (more than 8,000 in the past 20 years) by farmers on private lands. The highest priority identified was to stop population decline via strategies such as:
1. Improving and developing more accurate censusing and monitoring methods.
2. Monitoring population trends.
3. Conducting public education and outreach.
4. Developing a coordinated national strategy for dealing with problem cheetah.

For lion, the **Wild Management Goals and Strategies for Lion** working group identified the biggest problem to be accelerated decline of range available, causing population decrease (since 1980) from 700 individuals to approximately 300, presently. The highest priority action step was to maintain the lion's present habitat and prey base, particularly in Etosha and Kaudom, by communicating to the MET and the government about the importance of these habitats, especially improving park maintenance as specified in Park Management Plans.

The **Human/Livestock Interaction and Communication** working group identified general problem areas to be: stock loss from both lion and cheetah; farming practices and land use; communication; and education. The highest priority for action identified by this group was the reduction of stock losses by cheetah and lion. Priority strategies for resolving problems caused by cheetah included:
1. Protecting small stock with guard dogs, donkeys or herdsmen.
2. Synchronizing the livestock calving season with the game calving season.
3. Keeping calves less than 6 months old in protected camps and providing adequate prey base for cheetah to reduce the need to eat calves.
4. Removing bottom strands of cattle fence to allow free movement of certain small game species.
5. Free movement of small game species and managing other predators.

Priority action steps to address stock loss from lion included: upgrading and predator-proofing of fences along Etosha's boundaries; increasing the incentive to tolerate lion by promoting their positive value through trophy hunting and ecotourism; establishing a central coordinating office to facilitate communication among farmers with problem animals and hunting operators or game farmers who may want the animal; and the capture of problem lion for relocation outside the country.

The **Life History/VORTEX Modeling** working group determined that if the cheetah population continues to decline at the 4 to 7% annual rate experienced over the past 15 years, there is a 50 to 100% probability of extinction in the next 100 years. The population appears to have a robust growth potential of 10 to 15% per year if it is subjected to only natural mortality. Under these conditions the population could double in size in 5 to 7 years if left undisturbed. This working group recommended that it would be necessary to:

1. Manage the cheetah population on the farmlands so that 10% or less of the adult females and 20% or less of males are removed annually. For a population size of approximately 2,500 animals this would be about 60 to 70 adult females per year. This would provide a margin of safety for uncertainties in estimates of density, uncertainties in knowledge of natural female mortality rates, in female reproductive rates, in directions and rates of migration, and in estimates of fluctuations in natural mortality.
2. Removal of males needs to continue to be given preference over the removal of females in the control of problem animals in the farmland population. Population viability and growth rates are not as sensitive to male mortality rates over a wide range. Total annual adult male mortality rates of 30-35% will have no effect on population growth rates. It will be useful to further evaluate the genetic consequences of such a strategy.
3. Improve the estimates of annual female natural and especially removal mortality rates as a guide to possible population growth rate impacts and to provide management guidance on the number of removals that can be allowed and sustain a viable population. Reporting by the farmers of removals by sex will provide a useful estimate.
4. Improve estimates of the proportion of females not producing a litter (that survives to the age of 3-4 months) each year. This estimate and estimates of cub survival (observed litter size) to the age of about 1 year can serve as an indicator of environmental variation effects on reproduction. Correlation with environmental or habitat (prey density) data may provide a useful management index.
5. Evaluate the impact of continued excess loss of adult females during the dry phase years on stability of population size and on the management target for the population.
6. Estimate the confidence limits of the methods used to estimate population density, available habitat, and calculated population size as a basis for estimating the magnitude of change and the number of years of change required to detect different rates of population change (decline or increase). For example, what effort, frequency of measurement, and measurement reliability would be required to detect the 4-7% annual decline in population size estimated to have occurred since 1980? Estimates of these parameters can be done with modeling and statistical methods using currently available data and theory. These estimates would provide a basis for the amount of effort required to monitor the status of the population, to detect changes in the population, and to allow adjustments of management.

For lion, the **Life History/VORTEX Modeling** working group recommended that it was necessary to:

1. Estimate the confidence limits of the census methods as a basis for estimating the number of years required to detect different rates of population change (decline or increase) and as a basis for monitoring the population and adjusting management.
2. Analyze available data on litter size and cub survival on an annual basis to match with rainfall and provide an estimate of environmental variation to use in the models. These

measures also may provide an index of changes in prey availability and nutritional status of the population. Consider using these two parameters as a basis for monitoring the status of the population and as useful indices of the effects of management interventions.

3. Evaluate the impact of continued excess loss of adult females during the dry phase years on stability of the population size and on the management target for the population. Develop estimates of the excess losses that can be sustained by the population during the dry-phase years.
4. Evaluate possible inbreeding depression effects and the impact of the excess loss of subadult males and breeding structure on the rate of inbreeding. Modeling different mortality and breeding scenarios can start this.

The **Disease** working group agreed that disease is a potential threat to the viability of both lion and cheetah populations in Namibia. Three general needs were identified:

1. Defining the diseases that are threats to both the wild and captive populations.
2. Setting standards for disease surveillance and preventive measures.
3. Creating models of disease threats as catastrophes that could be modeled for both the Namibian lion and cheetah populations using VORTEX.

The highest priority identified by this group was defining the diseases that are real or potential threats to both lion and cheetah populations. For lion these included Feline Immunodeficiency Virus (FIV), canine distemper virus (CDV), and rabies. Infectious diseases in cheetah included anthrax (especially in Etosha) and, potentially, feline coronavirus, CDV, FIV, and rabies. Suggested ways of implementing this strategy included:

1. Determining the prevalence of infectious diseases in Namibia.
2. Determining the pathogenicity of strains of infectious diseases in Namibia, such as FIV and CDV.
3. Training Namibian veterinarians and laboratory personnel in the procedures to diagnose diseases in and conduct clinical pathology for lion and cheetah.
4. Training farmers and field personnel to collect biomaterials.
5. Defining the applied research projects to identify effective preventive measures.
6. Creating a captive management plan to minimize diseases.
7. Identifying funding to meet the needs for surveillance, *in situ* training, and applied research.

The working group then developed action steps, which, if approved by the MET, could be used to define disease threats.

The **Genetics** working group identified the main problem being the genetic and demographic security for the extant but small, isolated free-ranging populations of both cheetah and lion in Namibia. Of special concern for the cheetah was the lack of understanding of management consequences of having small founder populations on game farms/reserves. Two suggested solutions included:

1. The use of molecular genetic indices, including DNA analysis with mini- and micro-satellite probes when appropriate.
2. Consideration of facilitated genetic exchange and developing practical guidelines for selecting founders of known origin and for managing small populations based on

demographic simulation models.

The **Captive Populations** working group noted that there are two types of captive-held animals in Namibia: (a) Those permanently held in captivity (i.e., pets, tourism); or (b) those animals held temporarily before translocation. There are about six facilities holding lion, primarily for tourism, and 50 to 80 cheetah held in permanent captivity, the majority as pets. The Captive Populations working group suggested that the Namibian Government should consider appointing a commission comprised of representative parties (MET, farmers, hunters, veterinarians, NGOs, and others) to examine existing regulations for keeping captive animals (in light of PHVA recommendations) within the next 6 months, and then to promulgate appropriate legislation. It also was suggested that the Namibian government consider implementing a Cheetah Policy, with the information in this PHVA document used as a starting point in the development and elaboration of a cheetah management plan. Currently there is a lion policy that equally might be re-examined in light of the synthesized information resulting from the PHVA workshop. It is recommended that both these options be examined during the next 12 months.

The **Management Goals and Strategies, Disease** and **Captive Populations** working groups identified developing and expanding a Genome Resource Bank (GRB) for both lion and cheetah as a priority strategy. The cryopreservation in liquid nitrogen of biomaterials (e.g., eggs, embryos, blood, sperm) in a GRB is an emerging "tool" that has enormous implications for the assessment, conservation, and sustainable use of natural resources. A GRB is not established for the purpose of replacing living animals in nature or in zoos, but to support existing efforts to preserve a species with all its currently available genetic diversity. General considerations in establishing a Cheetah and Lion GRB were that these repositories be developed in accordance with guidelines established by the IUCN/SSC/CBSG.

On the last day of the workshop, the comprehensive set of problems, priorities, suggested strategies/solutions, and action steps for the conservation and management of Namibian cheetah and lion were reviewed, intensively discussed, and consensus reached on all, forming the basis of this document. We conclude that this is a first step for developing a systematic, regional conservation program for two of Namibia's most precious species.

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SECTION 1

INTRODUCTION AND OVERVIEW

Introduction and Overview

PHVA Workshop for the Namibian Cheetah and Lion

Introduction

Reduction and fragmentation of wildlife populations and habitat are occurring at an accelerating rate worldwide. For an increasing number of taxa, these factors result in small and isolated populations that are at risk of extinction. A rapidly expanding human population, now estimated at 5.77 billion, is expected to increase to 8.5 billion by the year 2025. In Namibia, the current human population is estimated at 1.6 million and, at its current rate of increase, is expected to double to 3.2 million in 26 years (Population Reference Bureau, 1996). This expansion and concomitant utilization of resources has momentum that cannot be stopped, with the result being a decreased capacity for all other species to exist simultaneously on the planet.

In Africa, as in the rest of the world, human activities increasingly threaten the survival of natural environments and wildlife populations. As these populations are diminished, their ecological roles in ensuring a well-balanced, regulated, and sustainable ecosystem also are reduced. Still, most conservation actions are directed toward habitat and reserve protection, rather than the conservation and management of the wildlife components that are critical to the long-term survival of individual ecosystems.

Single species management for threatened species can take a variety of forms:

- Protection from invasive organisms and pathogens
- Habitat modification and management (e.g., prescribed burning or provision of artificial watering sites)
- Reintroduction or translocation
- Assisted reproduction
- *Ex situ* breeding or propagation, either in-country or abroad

Species as the compositional unit of a community or ecosystem are a convenient and discrete unit of management, particularly when that taxon is threatened and requires species-specific management. A Population and Habitat Viability Assessment (PHVA) provides focus at the species level and provides a forum to bring collaborative specialties together to ensure a balanced, integrated approach to species conservation.

Wildlife managers realize that management strategies that will reduce the risk of species depletion must be adopted to ensure viable ecosystem functions. These strategies will include increased communication and collaboration in: habitat preservation; intensified information gathering in the field; investigating the ecological roles of key species; improving biological monitoring techniques; and, occasionally, scientifically managing captive populations that can interact genetically and demographically with wild counterparts. Successful conservation of ecosystems and wild species necessitates developing and implementing active management programs by people, governments, and non-government organizations (NGOs) that live alongside, and are responsible for, that ecosystem.

The PHVA Process

Effective conservation action is best built upon critical examination and use of available biological information, but also very much depends upon the actions of humans living within the range of the threatened species. Motivation for organizing and participating in a PHVA comes from fear of loss as well as a hope for the recovery of a particular species.

At the beginning of each PHVA workshop, there is agreement among the participants that the general desired outcome is to prevent the extinction of the species and to maintain a viable population(s). The workshop process takes an in-depth look at the species' life history, population history, status, and dynamics, as well as assesses the kinds of threats putting the species at risk.

One crucial by-product of a PHVA workshop is that an enormous amount of information can be gathered that, to date, has not been published. It is estimated that 80% of the useful information about a given species is in people's 'heads' and likely will never be published. All participants are equal in the PHVA process, recognizing the contributions of all people with a stake in the future of the species. Information contributed by ranchers, game wardens, scientists, field biologists, and zoo managers all carry equal importance. To obtain the entire picture concerning a species, all the information that can possibly be gathered is discussed by the workshop participants with the aim of reaching agreement on the current information. These data then are incorporated into a computer simulation model to determine: (1) risk of extinction under current conditions; (2) those factors that make the species vulnerable to extinction; and (3) which factors, if changed or manipulated, may have the greatest effect on preventing species extinction. In essence, these computer-modeling activities provide a neutral way to examine what is going on currently and what needs to be done in the future to prevent extinction.

The value of the PHVA process also lies in enhanced communication. People often have been working with the same species for years but may have never discussed important issues face to face. During the PHVA process, participants work in small groups to discuss key issues, whether predator management, disease, human-animal interactions, or other emerging topics. Each working group produces a brief report on their topic, which is included in the PHVA document resulting from the meeting. A successful PHVA workshop depends on determining an outcome where all participants, coming to the workshop with different interests and needs, "win" in developing a management strategy for the species in question. Local solutions take priority. Workshop report recommendations are developed by, and are the property of, the local participants.

The Namibian Cheetah - ***Laurie Marker Kraus***

Originally, cheetah were found from the Cape of Good Hope to the Mediterranean, throughout the Arabian Peninsula to the southern part of the former Soviet Union. Population numbers have declined from more than 100,000 in 1900 to approximately 9,000 to 12,000 free-ranging cheetah inhabiting a range now restricted to North Africa, the Sahel, and East and southern Africa. Fewer than one-third of the countries in which cheetah exist have viable populations. Two population strongholds remain: Kenya/Tanzania in East Africa and Namibia/Botswana in southern Africa. The cheetah's greatest hope for survival lies in the relatively undeveloped countryside of Namibia, home to the world's largest population. Even here the species numbers are thought to have declined by approximately 50 percent between 1980 and 1991, leaving a population of fewer than 2,500 animals.

Decreasing cheetah numbers throughout Africa are thought to be a result of declining habitat and prey base. As humans convert more and more of the cheetah's habitat into farmland for livestock production, human/cheetah conflicts have emerged. Although wildlife reserves and conservation parks have been set aside as a haven for wild animals to roam freely, for the cheetah such parks and reserves have led to direct competition with other large predators. Notably lion and hyenas may take up to 50% of cheetah kill and a large percentage of cheetah cubs, making it difficult to sustain a viable population.

As a result of this competition, most free-ranging cheetah are found outside protected areas. Surveys show that in Namibia, 70% of wildlife lives on private, commercial farmlands ranging from 5,000 ha to 15,000 ha (10,000 to 40,000 acres). Ninety-five percent of the cheetah population lives on these private lands, where prey is available and other large predators generally are absent. But private ownership of wildlife has caused unique problems for conservation. Historically, the cheetah has been viewed as a pest and a threat to the livelihood of livestock farmers, and it is legal in Namibia to shoot an animal that interferes with one's property and livelihood.

In the 1980s, because of a variety of circumstances that included severe drought, game populations declined by 50 percent and cheetah populations came into greater conflict with farmers and domestic livestock. Additionally, during this period, 80 percent of one of the cheetah's main prey, the kudu *(Tragelaphus strepsiceros),* died from a rabies outbreak. Combined, these events led cheetah to begin to prey on domestic livestock, resulting in increased conflict with the farmers who live-trapped the cats or shot them. By the latter part of the 1980s, the cheetah population had been reduced by more than half. The Convention in International Trade in Endangered Species (CITES) data report that between 1980 and 1991 more than 6,800 cheetah were removed from these farmlands and the conflict continues. The cheetah's survival requires all stakeholders in the future of the species to develop a clear understanding of each other's needs, with an aim to reach a compromise.

Since almost all huntable wildlife belongs to the landowners and has an economic value through live sale, meat production, and trophy hunting, wildlife conservation strategies are developed along with livestock and pasture management practices. Alternative farm management practices are being introduced to protect livestock from predators, including, but not limited to: placing donkeys with calving herds, as donkeys are aggressive and chase away cheetah; promoting more aggressive breeds of cattle; employing herders and large breeds of guard dogs; placing livestock in a kraal at night.

Molecular genetic studies have shown that the cheetah lacks genetic diversity, probably because of past inbreeding, which has limited its options for adapting to environmental change and challenges. Collaborative research conducted at the DeWildt Cheetah Breeding and Research Center in South Africa, the Wildlife Safari in Oregon (USA), and in the Serengeti National Park in East Africa revealed that cheetah have 10 to 100 times less genetic diversity than is normal in other cat or mammal species. Today's cheetah population is similar to laboratory mice that have been deliberately inbred for 20 generations.

Based primarily on studies of captive populations, the cheetah's genetic uniformity has led to reproductive abnormalities, high infant mortality, and increased susceptibility to disease. This disease susceptibility was demonstrated in the 1980s when viral outbreaks of feline infectious peritonitis almost destroyed several captive populations of cheetah.

The Namibian Lion - *Hu Berry*

Namibia is home to a unique and significant lion population that is seriously threatened by human conflicts, range loss, and potential disease threats. Although lion in Namibia represent only 1% of Africa's total population (estimated between 30,000 and 89,000), they are of tremendous tourism value within the country, and are an important conservation population. For example, approximately 43% of 280,000 tourists in 1993 visited Etosha National Park, where lion are a major attraction, and generated approximately N$500 million that year. For this and other reasons, the 200 lion remaining in Etosha are an invaluable and irreplaceable asset. Additionally, lion are important to the trophy hunting industry. Namibia is among only three African countries that still can offer the “big five” to hunters (lion, leopard, buffalo, white rhino, and elephant). The FIV-free status of lion in Etosha makes these populations invaluable to worldwide lion conservation.

Historically, lion ranged over most of the northern half of the country and partly in the east, west, and south. Few historical, quantitative population estimates are available, though total lion numbers were estimated at approximately 500 in 1975 and approximately 700 individuals in 1980. Since then, the Namibian lion population has been declining, and now is estimated at only 300 animals. This trend indicates that up to a 50% decline in lion numbers may have occurred over the past 15 years, although censusing techniques used in the 1970s and 1980s were less precise than those used currently, which may lend a margin of error to the above estimates. A complicating factor is that 85% of the lion in Namibia currently are restricted to two protected areas, the Etosha National Park (180 to 200 lion) and Kaudom Game Reserve (50 lion).

The lion in Namibia has only recently (1995) been classified as a “protected species” under the Nature Conservation Ordinance (No. 4 of 1975). Before this classification, the Ministry of Environment and Tourism had no formal method of monitoring the incidence of problem-animal hunting, or deterring farmers from killing lion when there was a perceived threat to them or their livestock.

Despite the importance of these regulations, many threats to the Namibian lion population exist. Livestock, agriculture, and the human population constitute the greatest sources of conflict for the lion. During the 30-year period from 1965 to 1994, at least 1,000 lion were reported to have been destroyed on farmlands bordering Etosha. The number actually may be considerably higher since (as described above) before the 1995 protected species classification, local landowners were not legally obligated to report lion kills.

Such human-lion conflicts may actually become even more frequent given the projected growth in Namibia's human population. Furthermore, 55% of Namibian citizens currently live adjacent to, or in, the areas where lion occur, and the majority of these people own livestock (cattle, goats, donkeys, and horses).

Another important factor affecting Namibia's lion is the isolated and fragmented nature of the populations. This isolation also places these populations at increased risk to the deleterious effects of small population size, such as increased inbreeding. Additionally, of lion reportedly killed on farmlands outside of Etosha, the majority have been sub-adult males. A marked decrease in this age class may seriously impact the demographics and long-term survival of the small population there. In the event of a catastrophe (such as a disease epidemic similar to the canine-distemper outbreak in the Serengeti), a small, isolated lion population may suffer greatly.

Initiation of the PHVA Process for the Namibian Cheetah and Lion

To address these and other problems facing the two species, a Population and Habitat Viability Assessment (PHVA) Workshop for the Namibian cheetah and lion was held from 11-16 February 1996 at the Otjibamba Lodge and the Hamburgerhof Hotel in Otjiwarongo, Namibia. The workshop was a collaborative endeavor of the Namibian Ministry of Environment and Tourism, the Cheetah Conservation Fund, the Felid Taxon Advisory Group (TAG) of the American Zoo and Aquarium Association (AZA), the AZA Cheetah and Lion Species Survival

Plans, and was facilitated by the IUCN/SSC Conservation Breeding Specialist Group. The meeting was hosted by the Cheetah Conservation Fund, Otjiwarongo, Namibia and generously sponsored by British Airways, White Oak Conservation Center, Columbus Zoo, NOAHS Center - Smithsonian Institution's National Zoo, Philadelphia Zoo, Fort Worth Zoo, Zoo Atlanta, Oklahoma City Zoo, Rio Grande Zoo, Houston Zoo, Caldwell Zoo, Franklin Park Zoo, Binder Park Zoo, and Nashville Zoo.

The PHVA Workshop - Day 1

Participants were welcomed, and the meeting was officially opened by His Excellency, Dr. Sam Nujoma, President of the Republic of Namibia (Appendix I). Mr. Kavetuna, Mayor of Otjiwarongo, and Mr. Marshall McCallie, U.S. Ambassador, welcomed the participants, followed by an informational session concerning Namibian conservation policy by the Honorable G.J. Hanekom, Namibian Minister of Environment and Tourism (MET) (Appendix II).

The first day's activities were attended by nearly 100 participants from 10 countries (Appendix III), including a representative group of the stakeholders in the future of the two species: Namibian MET officials, farmers, conservationists, and scientists. Overview presentations concerning the status of both the cheetah and lion, the role of conservancies in Namibia, problems facing commercial farmers, as well as presentations on small population biology and the goals of the workshop set the stage for the weeklong activities.

The first afternoon primarily was designed for dialogue pertaining to farmers' concerns; because of the rigorous needs in maintaining their farms, most could not attend the workshop after the first day. The farmers expressed their primary dilemma as determining how to maintain commercial livestock farms without being forced to kill cheetah and lion to protect their livelihoods. An hour-long discussion took place during which all stakeholders were able to voice their concerns to each other and to the Ministry, in an open forum.

This was followed by a brief presentation by the workshop facilitator on a suggested method for explicit communication of each stakeholder group's problems and needs in terms of the two species, so that each group could understand the other's perspective in relation to the cheetah and lion. Stakeholders then formed seven small, homogeneous groups of 6 to 10 people each: farmers with lion problems, ministry personnel, farmers with cheetah problems, and two groups each of conservationists and scientists. Each group was asked to list three to five of their most urgent problems relating to the species, with instructions to state them using consensually-reached, issue-based statements (e.g., "The critical problems for us are . . . " and to record them on flipcharts.

The second portion of the small group task centered on generating a discussion of needs rather than positions, also using statement format (e.g., "We need . . ."). Participants were instructed not to focus on solutions, as that would be a task during the rest of the workshop. Instead, they were asked to explicitly state their <u>own</u> needs, followed by a "why" statement. For example, rather than saying "We need more open communication" or "We need to retrieve carcasses of dead lion and cheetah," participants were asked to use statements such as "We need more open communication to understand in what way Ministry policies or initiatives help protect these species" or "We need to retrieve carcasses of dead lion/cheetah to analyze threats, such as disease, to our populations."

Working groups then posted their results and a representative from each group gave a brief synopsis of the problems and needs identified. A group of four participants, each representing one of the stakeholder groups, then synthesized and presented commonalties and differences between the problems and needs expressed by each of the four stakeholder groups. Several common themes clearly emerged:

1. Communication/education/cooperation

2. Basic research
    - identifying critical threats
    - long-term monitoring to detect population trends
    - range, habitat, and prey to ensure viable populations
    - global management of captive populations

3. Funding to implement #s 1 and 2

4. Economic considerations
    - impact
    - asset value of cheetah and lion
    - integrated wildlife and livestock management (land-use)
        - restricting range of cheetah and lion
        - practical solutions to the needs of people
        - evaluation of appropriate, sustainable land-use systems

The identified problems and needs of the individual stakeholder groups are identified on the next page.

MINISTRY

Problems

(1) The critical problem for us is uncertainty of impact of removals on both cheetah and lion populations.

(2) Another problem is incompatible land-use objectives within the range of large carnivores.

(3) A major problem is lack of resources to maintain effective communication with other stake-holders (resources: money, human, time)

Needs

(1) We need to understand the limiting factors for our cheetah and lion populations manage the populations.

(2) We need to improve the monitoring of cheetah and lion populations on a national scale to detect trends.

(3) We need to increase economic incentives for landholders to tolerate large carnivores.

(4) We need increased coordination within the farming community for collective planning and effective communication.

FARMERS WITH LION PROBLEMS

Problems

(1) Warthogs make holes in Etosha's perimeter fences. Erosion makes holes in the fences. Predators enter farm areas and create unacceptable losses to livestock.

(2) Etosha border fences are not being maintained regularly because of a lack of government funding and serious staff shortages.

(3) Farms bordering +/- 50 km of Etosha fence are essentially quarantine compounds. Lion have been removed out of this area to protect black-faced impala and roan antelope.

Needs

(1) We need proper, effective fencing.

(2) We need fences patrolled regularly.

(3) We need cooperation and communication improvement between farmers and Nature Conservation or MET.

(4) We need a unit to be created that deals with all three mentioned needs and is equipped with the relevant and necessary equipment and money to rectify the situation.

FARMERS WITH CHEETAH PROBLEMS

Problems

(1) The critical problem is the loss of livestock and wildlife.

(2) Many community disagreements result from differences in opinion concerning the conservation and management of cheetah.

(3) We have very little knowledge about cheetah.

(4) The cheetah is endangered and close to extinction.

Needs

(1) We need basic knowledge about how to solve the livestock losses to minimize the economic impact.

(2) New livestock/wildlife management techniques need to be introduced to reduce livestock/wildlife losses.

(3) We should have appropriate education for all.

(4) We need ways to make the cheetah a valuable asset to the farmer to compensate for economical losses.

(5) We need ways to bring people together to discuss disagreements.

(6) We need appropriate research of cheetah on farm lands/range lands to assist the farmer/conservationists.

(7). We need to monitor cheetah numbers to prevent the possible extinction of the cheetah.

CONSERVATIONISTS I

Problems

(1) There are inadequate ranges and fragmented populations.

(2) There is conflict between humans and predators.

(3) There is inadequate funding for the conservation of cheetah and lion.

Needs

(1) We need to secure suitable range to maintain viable populations.

(2) We need to foster communication to achieve an understanding of the potential value of the predators.

(3) We need to generate funding for the conservation of cheetah and lion.

CONSERVATIONISTS II

Problems

(1) There are diminishing numbers of cheetah and lion because of:
- -killing of predators
- -habitat loss
- -climatic fluctuations
- -diseases/genetic problems
- -consumptive utilization
- -no incentive to conserve.

Needs

(1) We need incentive to conserve.

(2) We need understanding of diseases and genetics.

(3) We need practical solutions to the needs of people.

(4) We need capital.

(5) We need education programs.

SCIENTISTS I

Problems	*Needs*
(1) There are gaps in our scientific knowledge of cheetah and lion survival and conservation.	(1) We need financial and other support to carry out studies to address these problems.
(2) There are gaps in our knowledge of appropriate sustainable land use systems to the benefit of wildlife and private land owners.	(2) We need to define and quantify the real importance of the critical threats to these species, including recognition of chronic and acute threats and the relative priorities of these threats.
(3) We have concerns about the long-term survivorship of the existing limited current lion population.	

SCIENTISTS II

Problems	*Needs*
(1) Our problem is the lack of information for both cheetahs and lions regarding natural history and ecology (farms and national parks).	(1) We need to gather baseline information for both species to allow making rational conservation management decisions.
(2) Our problem is a lack of long-term studies of infectious diseases of both the cheetah, lion and their prey.	(2) We need to establish long-term monitoring of infectious diseases that impact survival of viable populations and potential relocation.
(3) Our Problem is a lack of a management plan for captive cheetahs and lions.	(3) We need to establish a management plan for captive animals in Namibia for integration into existing global programs.

A good indication that stakeholders were successful in communicating their problems and needs, and in listening to the problems and needs of the other groups, is perhaps best reflected by a poem written by one of the farmers attending the workshop the first day (Appendix IV).

Continuation of the PHVA Workshop Process - Overview of Working Group Activities

The following 4 days of the PHVA focused primarily on the distribution, status and threats to the cheetah and the lion, and existing and proposed management strategies. The second day of the workshop began with a VORTEX computer simulation modeling demonstration on Etosha lion, and status reports on the cheetah and lion from Namibia, Zambia, and South Africa. Six working groups were established: Wild Management Goals and Strategies, Human/Livestock Interaction and Communication, Life History/VORTEX modeling, Disease, Genetics, and Captive Populations, each comprised of international as well as Namibian participants. The tasks of the working groups for the next 4 days then were to:

1. Identify the main issues and problems.

2. Determine goals in terms of identified issues and problems.

3. Develop promising strategies and solutions to address (1) and (2) in light of available data.

4. Prioritize the promising strategies and solutions in terms of the needs expressed by the various stakeholder groups on the first day of the workshop.

5. Turn the highest priority strategy into realistic action steps in terms of the ability to move forward in particular time frames (e.g., tomorrow; 1 month; 6 months; 1 year; 2 years, etc.) and, when possible, identify available and potentially available resources (e.g., people, time, potential in-kind contributions of equipment or training, potential funding sources).

6. Report daily (orally) on working group discussions so that input from other participants could be incorporated.

Working Group reports for cheetah and lion are included as Sections 2 and 3 of this document, respectively.

Summary of Working Group Recommendations

Cheetah

Although Namibia is believed to have the largest population of the endangered cheetah of any country in the world, it is thought to have declined to 2,000 to 3,000 animals from an estimated 6,000 in the early 1980s. Ninety percent of the national population exists on private lands, where many are killed as livestock and game predators.

For cheetah, the **Wild Management Goals and Strategies** working group noted the following problems (in order of descending priority):

1. Population decline.

2. Killing of significant numbers of cheetah (more than 6,000 in the past 20 years) by farmers on private lands.

3. The need for a coordinated national strategy for dealing with the disposition of problem cheetah.

For cheetah, the highest priority action identified by the Wild Management Goals and Strategies working group was to stop the population decline via strategies such as: improving and developing more accurate censusing and monitoring methods; monitoring population trends; and conducting public education and outreach.

Other suggested strategies to deal with (2) and (3) respectively were: minimizing conflicts on communal lands and commercial farmlands and development of a management program for problem cheetah trapped on private farms and communal areas. Details of the problems identified for both species, as well as specific suggested strategies and ways to implement these for cheetah, are outlined in the Management Goals and Strategies Working Group Report in Section 2.

The working group on **Human/Livestock Interaction Communication** identified general problem areas as: stock loss to the cheetah; farming practices and land use; communication; and education. The highest priority for action identified by this group was the reduction of stock losses by cheetah.

Cheetah kill small stock such as goats, sheep and cattle calves. Farmers may tolerate a small percentage loss to cheetah, however some losses are considered intolerable. In 1994, 74 cheetah were reported to be killed by farmers, with about half of these occurring in the Otjiwarongo district. Cheetah may be blamed for losses caused by other predators, such as lynx and jackals. On game farms, the calves of wild species such as sable, eland, and roan also are killed by cheetah, as well as small game species such as springbok *(Antidorcas marsupialis),* impala *(Aepyceros melampus),* and blesbok *(Damaliscus dorcas).*

Promising priority strategies for resolving these problems included: protecting small stock with guard dogs, donkeys, or using herdsmen; synchronizing the livestock calving season with the game calving season so that losses can be reduced by "swamping" the predators in the hope that cheetah will hunt natural prey rather than domestic animals; controlling calves under 6 months of age in a protected camp; providing adequate prey base for cheetah to reduce the need to eat calves; removing bottom strands of cattle fence to allow free movement of small game; and controlling other predators, among others.

Estimates of habitat and population numbers were derived in both the **Life History/VORTEX Modeling** group through consensus of field biologists with data. Model output, as with any model, is limited by the input. The biological information for the cheetah population came from the studies of Laurenson et al. (1992), Caro (1994), Marker-Kraus et al. (1996), Nowell and Jackson (1996), and personnel working in the Ministry of Environment and Tourism (MET) who participated in this PHVA Workshop. The sensitivity of the population dynamics to interactions in variations of adult female mortality, proportions of males killed each year, the frequency and severity of catastrophes, and proportion of females with no litter each year were examined. The telemetry study provided initial crude estimates of male and female mortality rates with male rates about double those of the females. Mean litter size of off spring 1 to 6 months old was 3.7, and it is likely that the birth mean litter size is greater.

Results from modeling suggested that if the Namibian cheetah population continues to decline at the 4 to 7% annual rate experienced over the past 15 years, there is a 50 to 100% probability of extinction in the next 100 years. The population appears to have a robust growth potential of 10 to 15% per year if it is subjected to only natural mortality. Under these conditions the population could double in size in 5 to 7 years if left undisturbed.

As such, priority recommendations of the **Life History/VORTEX Modeling group** were:

1. Manage the cheetah population on the farmlands so that 10% or less of the adult females and 20% or less of males are removed annually. For a population size of approximately 2,500 animals this would be about 60 to 70 adult females per year. This would provide a margin of safety for uncertainties in estimates of density, uncertainties in knowledge of natural female mortality rates, in female reproductive rates, in directions and rates of migration, and in estimates of fluctuations in natural mortality.

2. Removal of males needs to continue to be given preference over the removal of females in the control of problem animals in the farmland population. Population viability and growth rates are not as sensitive to male mortality rates over a wide range. Total annual adult male mortality rates of 30-35% will have no effect on population growth rates. It will be useful to further evaluate the genetic consequences of such a strategy.

3. Improve the estimates of annual female natural and especially removal mortality rates as a guide to possible population growth rate impacts and to provide management guidance

on the number of removals that can be allowed and sustain a viable population. Reporting by the farmers of removals by sex will provide a useful estimate.

4. Improve estimates of the proportion of females not producing a litter (that survives to the age of 3-4 months) each year. This estimate and estimates of cub survival (observed litter size) to the age of about 1 year can serve as an indicator of environmental variation effects on reproduction. Correlation with environmental or habitat (prey density) data may provide a useful management index.

5. Evaluate the impact of continued excess loss of adult females during the dry phase years on stability of population size and on the management target for the population.

6. Estimate the confidence limits of the methods used to estimate population density, available habitat, and calculated population size as a basis for estimating the magnitude of change and the number of years of change required to detect different rates of population change (decline or increase). For example, what effort, frequency of measurement, and measurement reliability would be required to detect the 4-7% annual decline in population size estimated to have occurred since 1980? Estimates of these parameters can be done with modeling and statistical methods using currently available data and theory. These estimates would provide a basis for the amount of effort required to monitor the status of the population, to detect changes in the population, and to allow adjustments of management.

The **Disease** Working Group agreed that disease is a threat to future viability of cheetah populations in Namibia. Three general needs were identified: defining the diseases that are threats to both the wild and captive populations; setting standards for disease surveillance and preventive measures; and creating models of disease threats as catastrophes that could be modeled using VORTEX.

The highest priority identified by this group was defining the diseases that are real or potential threats to cheetah populations. Infectious diseases in cheetah included anthrax (especially in Etosha) and potential threats of feline coronavirus, CDV, FIV, and rabies. Other potential disease threats were identified and are listed in the Disease working group report.

Suggested needs toward implementing this strategy included: determining the prevalence of infectious diseases in Namibia; determining the pathogenicity of strains of infectious diseases in Namibia such as CDV and FIV; training Namibian veterinarians and laboratory personnel in the procedures to diagnose diseases in and carry out clinical pathology for cheetah; training farmers and MET field personnel to collect biomaterials; defining the applied research projects to identify effective preventive measures; creating a captive management plan to minimize diseases; and identifying funding to meet the needs for surveillance, *in situ* training, and applied research.

Once these were identified, the working group then developed recommendations, which if approved by the MET, could be used to define disease threats:

1. Summarizing all available retrospective data and literature to define historic epidemics.

2. Informing veterinarians of proposed monitoring programs.

3. Conducting priority screening for diseases of potential concern with stored serum samples.

4. Initiating prospective disease monitoring through the collection, evaluation, and banking of biomaterials.

5. Evaluating habitat and environmental factors that concentrate pathogens.

6. Submitting a grant to NGOs and securing funding sources for a comprehensive, long-term disease-monitoring project for cheetah in Namibia.

7. After 3 years, collating all prospective and retrospective data to redefine the disease threats to Namibian cheetah, with results of this collation used to reassess the disease threats to Namibian cheetah populations and to define new priorities for surveillance and research.

Primary problems for cheetah identified by the **Genetics** working group were:

1. There exists a proven sensitivity of the cheetah's ancestors, and possibly the current population, to demographic reduction and genetic homogenization.

2. Physical/health problems have been observed in free-ranging cheetah, such as abnormal sperm characteristics which are developmental in origin, tooth/jaw anomalies, or kink in tail vertebrae. It is important to determine if whether these anomalies are indicative of inbreeding depression, infectious diseases, poison, or other factors and if their frequency is changing. Further, undesirable physiological traits may be reduced through outbreeding.

3. There is a lack of understanding of the management consequences of having small founder populations of cheetah on game farms/reserves.

4. The cheetah is a Namibian national treasure that also is a fascinating subject for genetic research. However, there is a lack of geneticists within Namibia with access to molecular biology technologies and funding sources to investigate these questions.

Suggested solutions to these problems (in order of priority) included:

1. Developing practical guidelines (by interested game farm managers and farmers aided by information obtained from the cheetah source) for selecting founders of known origin and for managing small populations based on demographic simulation models.

2. Assessing and recognizing components of relative fitness that may reflect historic or recent inbreeding; encouraging and sponsoring interested Namibian students/interns to train in laboratories of experienced wildlife geneticists outside of Namibia, allowing them to return and apply their training to the study of indigenous species.

3. Testing geographically isolated populations for the extent of phylogenetic distinctiveness.

4. Establishing controlled matings in captive settings using intercrosses between animals from geographically distinct populations, initially between *A. j. jubatus* and *A. j. raineyi* to evaluate the offspring for fitness; and identifying the cause of the historic bottleneck in order to anticipate and/or avoid a similar event in the future.

These problems and suggested solutions for cheetah are elaborated in the **Cheetah Genetics** working group report in Section 2.

The **Captive Populations** working group began with attempting to define the captive population of Namibian cheetah. For the purposes of this document, a captive population was considered to be comprised of non-free-ranging animals managed on an individual basis, and which were not self-sufficient. In this context, there were two types of captive-held animals: (a) those permanently held in captivity (i.e., pets and tourism); or (b) those held temporarily before translocation. There are 50 to 80 cheetah held in permanent captivity in Namibia, the majority as pets. The remainder are used for exportation and tourism, with most of these having originated as problem animals (i.e., preying on livestock).

Namibia currently has minimum legislation regulating facilities that hold cheetah. It was suggested that it might be appropriate to review current Namibian legislation and policy on maintaining animals in captivity, with an internal evaluation of legal standards concerning handling and housing of animals moving into and within captivity, possibly through a coordinating body. The **Captive Populations** working group suggested that the Namibian Government should consider appointing a commission comprised of representative parties (MET, farmers, hunters, and others.) to examine existing regulations, in light of the recommendations of the PHVA, within the next 6 months and then to promulgate appropriate legislation.

The Namibian government should consider implementing a cheetah policy with the information in this PHVA document used as a starting point in the development and elaboration of a captive cheetah management plan to be developed over the next 12 months.

The **Captive Populations** working group also suggested that the Namibian government should consider the establishment of a central representative coordinating body, whose function would be to set standards for the captive management of cheetah (and lion) within Namibia. This possibly could be implemented within the next 12 months. In the interim, the government might consider a program to assess the general health and disease status of the existing captive cheetah.

Lion

The **Wild Management Goals and Strategies** working group identified general problem areas concerning lion as: accelerating decline of population and range; the loss of a significant number of lion (~1,000 over the past 20 years), particularly subadults, as a consequence of being killed by farmers; and an increasing incidence of FIV recorded in populations in Africa which would place the Namibian population under threat if FIV spreads. The working group identified as the highest priority problem the accelerated decline and range available to lion, with a possible concomitant decline in the population from 700 animals in the 1980s (note: these estimates may reflect different censusing techniques used in the past) to approximately 300 presently. The potential action strategies identified by the working group to address this problem (in descending order of priority) were:

1. Maintaining the lion's present habitat and prey base, particularly in Etosha and Kaudom, by communicating to MET and the government the importance of Etosha and Kaudom for the continuing viability of lion populations in Namibia and by carrying out maintenance as specified in Park Management Plans.

2. Implementing needed population research and monitoring programs in both Etosha through research, seeking of resources and funding, and monitoring, and through training of the Kaudom MET ranger staff in specific monitoring techniques.

Other goals included minimizing conflict on boundaries of the lion's existing protected range and maintaining an FIV-negative population, at least in Etosha. Specific strategies and suggested action steps to reach the outlined goals for lion are delineated in the **Wild Management Goals and Strategies** working group report (Section 3).

The working group on **Human/Livestock Interaction and Communication** identified general problem areas as: stock loss from lion; farming practices and land use; communication; and education. The highest priority for action identified was the reduction of stock losses. Cattle losses on the southern border of Etosha may be in the range of 10 to 12 cattle per farmer per year per 500 head of cattle. In eastern Etosha, cattle losses may in the range of 50 to 60 cattle per farmer per year per 500 head. The reported number of lion killed by farmers in Etosha is approximately 20 per year, but could be as many as 40. Losses of livestock to lion also occur in Bushmanland, Caprivi, Kavango, and Damaraland.

Promising priority action steps identified by this working group to address stock loss from lion included:

1. Upgrading and predator-proofing of fences.

2. Increasing the incentive to tolerate lion by promoting their positive value through trophy hunting and ecotourism.

3. Establishing a central coordinating office to facilitate communication between farmers with problem animals and hunting operators or game farmers who may want the animal.

4. The capture of problem lion for relocation outside the country.

The **Life History/VORTEX modeling** working group developed simulation scenarios for the Etosha lion population using parameter values from the 6 year study (1980 to 1986) of this population by H. Berry, historical census and litter size data on the population, and information about lion killed on lands adjoining the Etosha National Park. The sensitivity of the population dynamics to interactions in variations in cub mortality, adult female mortality, carrying capacity, litter size, and inter-birth interval were examined. The impacts of several catastrophes, including an epidemic of CDV which then became endemic to the population, were modeled.

A base scenario for the population, constructed from the field data, indicates that (under the parameter values prevailing during a dry-phase) the lion population has a negative growth rate. Thus long-term survival of the population depends upon improved reproduction during the wet-phase years. The demographic impact of the numbers of lion killed during the years 1980 to 1985 is nearly sufficient to account for the observed 50% decline in the total population. If habitat conditions continue and if adult females continue to be subjected to excess mortality by hunting, the population (a) may continue to decline and (b) will be vulnerable to the effects of unexpected mortality events like epidemics. An increase in mortality caused by the catastrophic introduction of CDV into the population could reduce the mean population growth rate (r) by 0.034, substantially increase the risk of extinction of the population.

Recommendations for action developed from the modeling included:

1. Estimate the confidence limits of the census methods as a basis for estimating the number of years required to detect different rates of population change (decline or increase) and as a basis for monitoring the population and adjusting management.

2. Analyze available data on litter size and cub survival on an annual basis to match with rainfall and provide an estimate of environmental variation to use in the models. These measures also may provide an index of changes in prey availability and nutritional status of the population. Consider using these two parameters as a basis for monitoring the status of the population and as useful indices of the effects of management interventions.

3. Evaluate the impact of continued excess loss of adult females during the dry phase years on stability of the population size and on the management target for the population. Develop estimates of the excess losses that can be sustained by the population during the dry-phase years.

4. Evaluate possible inbreeding depression effects and the impact of the excess loss of subadult males and breeding structure on the rate of inbreeding. Modeling different mortality and breeding scenarios can start this.

The **Disease** Working Group agreed that disease is a threat to the potential viability of lion populations in Namibia. As for cheetah, three general needs were identified: defining the diseases that are threats to both the wild and captive populations; setting standards for disease surveillance and preventive measures; creating models of disease threats as catastrophes that could be modeled for the Namibian lion populations using VORTEX.

The highest priority identified by this group was defining the diseases that are real or potential threats. For lion these included FIV, CDV, and rabies. Other potential disease threats also were identified and listed in the working group report.

Suggested needs toward implementing this strategy included: determining the prevalence of infectious diseases in Namibia; determining the pathogenicity of strains of infectious diseases in Namibia such as FIV and CDV; training Namibian veterinarians and laboratory personnel in the procedures to diagnose diseases in lion; training farmers and field personnel to collect biomaterials; defining the applied research projects to identify effective preventive measures; creating a captive management plan to minimize diseases; and identifying funding to meet the needs for surveillance, *in situ* training, and applied research.

Once these were identified, the working group then developed action steps, which if approved by the MET, could be used to define disease threats:

1. Summarizing all available retrospective data and literature to define historic epidemics.

2. Informing veterinarians of proposed monitoring program.

3. Conducting priority screening for diseases of potential concern with stored serum samples.

4. Initiating prospective disease monitoring through the collection, evaluation, and banking of biomaterials.

5. Evaluating habitat and environmental factors that concentrate pathogens.

6. Submitting a grant to NGOs and securing funding sources for a comprehensive, long-term disease-monitoring project for lion in Namibia.

7. After 3 years, collating all prospective and retrospective data to redefine the disease threats to Namibian lion, with results of this collation used to reassess the disease threats to Namibian lion populations and to define new priorities for surveillance and research.

The **Genetics** working group defined several basic problems for Namibian lion, listed below in order of descending priority:

1. There is a question as to the genetic and demographic prognosis for the free-ranging populations of lion in Namibia.

2. Unusual behavior and pride structure have been observed among the Etosha lion. Additionally, there is an imbalance in age/sex ratio in the reported destruction of lion on farms bordering Etosha National Park (50% are subadult males). A lack of parentage and kinship data makes it difficult to interpret these observations and to assess the impact of the loss of large numbers of subadult males.

3. Etosha lion may be a recognizable subspecies that would be unsuitable as a source of genetic material to supplement depleted South African populations. The animals are unique in their FIV-free status and have the potential to be an invaluable resource for injecting new genetic material into compromised lion populations outside Namibia.

4. There is a lack of understanding of the management consequences of having small founder populations of lion on game farms/reserves.

Suggested solutions/strategies to address the above included the use of molecular genetic indices, particularly DNA analysis with mini- and micro-satellite probes with appropriate analyses, and consideration of facilitated genetic exchange. Details of these analyses are found in the lion **Genetics** working group report (Section 3).

The **Captive Populations** working group began with attempting to define the captive population of Namibian lion (as described above for cheetah). There are approximately six facilities holding lion in Namibia (totaling 50 to 80 lion), primarily for tourism.

1. Namibia currently has minimum legislation regulating facilities that hold lion. It was suggested that it would be appropriate to review current Namibian legislation and policy on maintaining animals in captivity, with an internal evaluation of legal standards concerning handling and housing of animals moving into and within captivity, possibly through a coordinating body. The **Captive Populations** working group suggested that the Namibian government consider appointing a commission comprised of representative parties (MET, farmers, hunters, veterinarians, NGOs, and others.) to examine existing regulations for keeping captive animals, in light of the recommendations of the PHVA, within the next 6 months, and then to promulgate appropriate legislation.

2. The Namibian government should consider re-examining current lion policy in light of the synthesized information resulting from the PHVA workshop.

The Namibian government should consider the establishing a central representative coordinating body, whose function will be to set standards for the captive management of lion within Namibia. This could be implemented within the next 12 months. In the interim, the government should consider a program to assess the general health and disease status of the existing captive lion populations.

Development of **Genome Resource Banking (GRB)** for both cheetah and lion was identified as a priority strategy by the **Wild Management Goals and Strategies, Disease,** and **Captive Populations** Working Groups. The three working groups agreed that there are several practical and applicable uses of a GRB to facilitate cheetah and lion conservation. A GRB, is the <u>organized</u> collection, storage and use of biomaterials, especially sperm, embryos, tissues, blood products, and DNA. The cryopreservation of such materials is an emerging "tool" that has enormous implications for the assessment, conservation, and sustainable use of natural resources. A GRB is not established for the purpose of replacing living animals in nature or in zoos, but should have as its mission the support of existing efforts to preserve a species with all its currently available genetic diversity (see lion section below). An organized GRB could serve to provide a repository of frozen gametes, embryos, tissues, blood products, and DNA. The value of a GRB for a wild population could be enormous by helping to provide 'insurance' against catastrophes, especially emerging diseases, natural disasters and social/political upheaval. The cheetah and lion populations may suddenly become infected with sinister viruses, similar to the recent canine distemper epidemic that decimated the East African lion population. The availability of frozen serum and tissue that have been collected over time could be used to retrospectively identify the onset and cause of diseases that affect cheetah and lion. Pathogen-free gametes and even embryos could be made available to re-derive disease-free populations. Specific recommendations concerning the needs for cheetah and lion GRBs are included as Appendix V. General considerations in establishing GRBs were:

1. A GRB Action Plan should be developed in accordance with guidelines established by the IUCN - The World Conservation Union's Conservation Breeding Specialist Group.

Such documents detail the need for establishing a GRB and the important issues related to collection, storage, ownership, accessibility and use of biomaterials. Because a GRB Action Plan is being developed in North America under the umbrella of the Cheetah Species Survival Plan (SSP), it is recommended that collaboration between both regions be considered in the development of the proposed Cheetah GRB Action Plan. It is recommended that this proposed formal cooperative plan be initiated within 1 year with the initial primary partners being the Namibian M E T, the Cheetah Conservation Fund, the North American Cheetah and Lion Species Survival Plans (SSPs), and other relevant conservation organizations as determined by the Ministry of Environment and Tourism.

2. The biomaterials collected from cheetah and lion living on private or public lands should be the property of the government (country) of Namibia. It is recommended that the MET-Directorate of Resource Management make the final decision about the disposition of biomaterials. This will be controlled, in part, through the export permit process. Details of this process could be considered and set forth in the action planning document to be developed.

3. It is recommended that the scientific collection and storage of all biomaterials for cheetah initially might be coordinated by the Cheetah Conservation Fund in collaboration with Namibian State Veterinarians within the Ministry of Agriculture. Biomaterials from lion might be coordinated by the Namibian MET and the Namibian State Veterinarians within the Ministry of Agriculture. Establishing and securing a Cheetah GRB and a Lion GRB, including a site for secondary storage (as a second insurance site) might accomplish this. The coordinators might distribute the material by acting as a liaison between the MET, local veterinarians, interested scientists, zoos and other relevant organizations worldwide.

4. It is recommended that no monetary value be placed on any biomaterials to discourage the commercialization, or worse, the capture and exploitation of cheetah and lion. The cost of establishing and operating the proposed GRB might readily be supported by institutions throughout the world interested in conserving cheetah and lion. For example, workshop participants from North American zoos are confident in their ability to secure some funding to support the proposed Namibian GRB program. Additionally, it is recommended that the Ministry of Environment and Tourism consider accepting 'in-kind' support for such a program in the form of donated equipment.

5. Further research can enhance the efficiency of assisted reproduction in lion using cryopreserved sperm (e.g., hormonal stimulation of estrus and ovulation, time of ovulation and time of insemination using frozen-thawed spermatozoa).

6. As the proposed GRB Action Plan is prepared, it is recommended that the distribution and accessibility to biomaterials in the GRB might be made more readily available to organizations that are contributing to conservation programs in Namibia, either through direct monetary support of high priority programs such as those of the Cheetah

Conservation Fund or through providing in-kind support and training.

7. The MET-Directorate of Resource Management, the Cheetah Conservation Fund and other relevant national organizations (as determined by the MET) should receive full acknowledgment by any individual or organization that uses biomaterials from the proposed GRB. Furthermore, any offspring produced from the use of cryopreserved gametes or embryos should remain the sole property of Namibia, in part for the purpose of documenting and advertising the contributions of Namibia to conserving one of its most precious natural resources.

On the last day of the workshop, the comprehensive set of problems, priorities, suggested strategies/solutions, and action steps for the conservation and management of Namibian cheetah and lion were reviewed, intensively discussed, and consensus reached on all. These form the basis of the working group reports that comprise Sections 2 and 3 of this document.

POPULATION AND HABITAT VIABILITY ASSESSMENT FOR THE NAMIBIAN CHEETAH (*Acinonyx jubatus)* AND LION *(Panthera leo)*

11-16 February 1996
Otjiwarongo, Namibia

Workshop Report
February 1997

SECTION 2

WORKING GROUP REPORTS - CHEETAH

Wild Management Goals and Strategies Working Group Report - Cheetah

Kallie Venkze, Daniel Kraus (facilitators), Trygve Cooper, Marshall Howe, Luke Hunter, Sandy Hurlbut, Peter Jackson, Jim Teer, Heiko Theis, Bernard Ziess

Problem 1: Although Namibia has the most endangered cheetahs of any country in the world, the population is believed to have declined to only 2,000 to 3,000 animals from an estimated 6,000 in the early 1980s, as over a 10-year period nearly 7,000 cheetah were removed from the population. Estimates of population size are not statistically reliable because effective surveys have not been conducted. Ninety percent of the national cheetah population exists on private lands, where many animals are killed as livestock and game predators.

Goal: Maintain current cheetah population numbers in Namibia.

Strategy 1. Improve/develop accurate censusing and monitoring.
Action Step: Workshop--CCF will coordinate a meeting of MET, NGO's, statisticians, field biologists and population biologists during the next 12 months to investigate the practical methods of surveying the cheetah population nationally, with consideration of funding and personnel needed.

Strategy 2. Monitor population trends.
Action Step: Implementation--Implement the censusing and monitoring program on a regional and national level.
Demography--Record critical demographic parameters of cheetah (live and dead) removed from the farmlands. The above workshop will coordinate data collection.

Strategy 3. Conduct public education and outreach.
Action Step: Education--NGOs will continue to expand existing educational outreach programs nationally, and involve environmental education centers in outreach efforts.

Problem 2: Private land owners farming livestock and game suffer depredation by cheetah and complain of lack of assistance from MET. Significant numbers of cheetah (>6,000 in the past 20 years) have been killed on private lands since the 1980s.

Goal: Minimize conflicts on communal lands and commercial farmlands.

Strategy 1. Develop long-term economic incentive to tolerate cheetah by:
Action Step: Continue the encouragement of conservancies through meeting of conservancy representative with farmers associations.

Action Step: Discussions among MET, NGOs and farmers should take place on the sustainable utilization of cheetah,

Action Step: Tourism should be encouraged.

Strategy 2. Promote land use methods that stimulate greater wildlife numbers.
Action Step: Land use methods will be promoted through newsletters, the media, articles in agricultural journals, and through the Conservancy Association.

Strategy 3. Increase public awareness of the value of cheetah in natural ecosystems as a national treasure.
Action Step: Awareness will be promoted through education programs by NGOs, environmental education Centers and the media.

Problem 3: Although farmers trap many 'problem' cheetah, there is no coordinated national strategy for the disposition of these animals.

Goal: Develop a management program for problem cheetah trapped on private farms and in communal areas.

Strategy 1. Identify specific sites for temporarily holding captured cheetah.
Action Step: Various sites will be researched and designated as holding areas.

Strategy 2. Identify other cheetah populations nationally and internationally in need of supplementation.
Action Step: NGOs will be responsible for identification of areas in need of supplementation.

Strategy 3. Expand the existing communication network, so that availability of captured cheetah is quickly communicated to others, both nationally and internationally.

Action Step: Communication will be increased between NGOs, MET and veterinarians.

Strategy 4. Establish funds for cheetah translocation projects.
Action Step: NGOs will seek specific funding for cheetah translocation.

Human/Livestock Interaction with Predators, Communication and Education Working Group Report - Cheetah

Kadzo Kangwana (facilitator), Helmut Ackermann, Dolly Ackermann, Piet Burger, Jochen Hein, Paul Jessen, Charles Phiri, Judy Storm

The group started by identifying problems that occur at the human/livestock interface with predators:

* Stock loss
* Poor communication skills among stakeholders
* Land carrying capacity for cheetah
* Lack of environmental education in schools
* Lack of environmental understanding by farmers/citizens
* Incompatible farming methods
* Perceived lack of support from the Ministry of Environment & Tourism
* Game-proof fencing ineffective against cheetah
* Veterinary fence impedes movement of game
* Lack of extension workers
* Extermination of predators by farmers
* All stock loss blamed on predators
* Breeding seasons are not specific so calves (prey) are present throughout the year

These problems were grouped and tackled under the following headings: Stock Loss; Land Use and Farming Practices; and Communication and Education and Changing Attitudes.

Under each of these headings, the problems were described and action steps outlined.

STOCK LOSS

Stock Loss from Cheetah

The problem: Cheetah kill small stock, especially goats, sheep and cattle calves. Farmers may tolerate a small percentage loss to cheetah, however some losses are intolerable. In 1994, 74 cheetah were reported by MET as killed by farmers, about half occurring in the Otjiwarongo District. On game farms, cheetah also kills calves of wild species such as sable, eland, and roan. Cheetah also prey upon natural populations of small game species, including springbok

(Antidorcas marsupialis), impala *(Aepyceros melampus)*, and blesbok *(Damaliscus dorcas)*. Frequently, cheetah are blamed for losses caused by other predators (e.g., caracal, *Felis caracal* and jackal, *Canis mesomelas).* Small livestock also can be lost to aardvark *(Orycteropus afer)* dens.

Action Steps:

1. Protect small stock with guard dogs, donkeys, or herdsmen.
2. Synchronize calving season as losses can be reduced by "swamping" the predators. Try to coincide calving with peaks in wild species births so that cheetah will go for the natural prey rather than the domestic animals.
3. Maintain calves less than 6 month of age in a protected camp.
4. Provide adequate prey base for cheetah to reduce their need to kill livestock.
5. Remove bottom strands of cattle fence to allow free movement of small game.
6. Control other predators more effectively.

LAND USE AND FARMING PRACTICES

Problem: 1 Many cattle farms are closely located to protected areas which are a key conservation area for cheetah.

Action Step: Change the policy and restrictions on these lands to allow these farmers to have the option to convert to game farming.

Problem 2: Under current farming breeding practices, most farmers have many breeding herds spread across the farm throughout the year, which reduces protection ability and increases the probability of losing stock.

Action Step: Breeding herds should be concentrated in one area, which is more easily protected. A large herd of animals easily flusters the cheetah. By coordinating livestock breeding with natural breeding in wild ungulate populations, predators are swamped with available prey during a narrow time window. This, in turn, reduces the likelihood that cheetah will kill livestock rather than natural prey. A safe calving area also should be established near the farmer's house, a small camp, or within a predator-proof enclosure. Breeding of more aggressive cattle breeds should be encouraged; these breeds tend to be more aggressive and will therefore better protect their calves.

Problem 3: There is bush encroachment as a result of overstocking. Once the land is bush-encroached, there is less grazing land for livestock and the wild game numbers are reduced, thus providing less prey for the cheetah. This in turn can increase cheetah predation on livestock.

Action Step: Livestock carrying capacity varies from area to area. Carrying capacities set by the Ministry of Agriculture (1962) must be revisited. A farmer needs to identify how many cattle his/her land can support. Carrying capacity also must be considered on an annual basis and according to this capacity, each farm must be stocked correctly to decrease overgrazing and the deterioration of the land.

Problem 4: Specifications laid down by the Land Bank are outdated. These specifications prevent "environmentally friendly" farming. For example, the Land Bank will not provide a soft loan to a farmer to combat bush encroachment by using manual labor. However, a loan will be provided to farmers using herbicide to remove bush. Additionally, loans cannot be obtained for game farmers, but can be secured by cattle farmers.

Action Steps: Land Bank restrictions must be changed to allow flexibility.

EDUCATION

Problem: There is a general lack of understanding about environmental issues and conservation challenges.

Action Step: The importance of conservation challenges, knowledge of ecology, importance of wildlife and benefits of conserving wildlife must be stressed to the public.

Within the schools (children):

1. Promote inclusion of environmental science in the syllabus throughout the school curriculum. This approach now is being promoted by some NGOs, but the Ministries must become more involved. The subject must not be considered as a soft/easy option, but rather an imperative to education.
2. Encourage school participation on world awareness days (e.g., water day).
3. Promote children's literature on the environment by NGOs and Ministries.
4. Promote use of nature trails and outdoor awareness camps during school holidays and the use of environmental education centers.
5. Increase the number of environmental education centers within the country. These centers need to be evenly distributed throughout Namibia.
6. Promote wildlife clubs and action groups within the schools.
7. Promote field trips to institutions such as the CCF, game parks, crocodile farms, or just natural areas.
8. Study specific animals under the umbrella of the school syllabus.

Amongst farmers:

1. Promote the importance of cheetah conservation and explain the problems. Also provide education on cheetah life history and behavior. This could be accomplished by NGOs and the Ministry of Environment (extension workers).

2. Create a national awareness for the importance of cheetah (e.g., Namibia is the cheetah capital of the world), use the mass media (e.g., television, radio, public displays at shows, create slogans - “welcome to cheetah world!”).
3. Educate about conservation in general, emphasizing whole ecosystems and how all life forms interact.
4. Convene information days on a specific species where farmers are invited and speeches and slide shows are given.
5. Arrange for experts to attend farmers’ association meetings to speak about conservation issues, new farming practices and species.

COMMUNICATION

Problem 1: There is a lack of communication between: (1) farmers and the MET, (2) farmers and farmers, (3) different departments within the same Ministry, (4) among ministries, (5) NGOs and ministries, (6) between NGOs and farmers. The response time between reporting a problem and receiving assistance is excessive.

Action Steps:

1. All concerned organizations should identify a 'point' person responsible for assisting in resolving problems. Problems should be tackled within the constraints of Ministry staff shortages by allowing NGOs or other interested parties to help. The Ministry should act in a coordinating role while being flexible as to who implements activities.
2. Encourage extension officers from the Ministry of Agriculture to visit farmers.
3. Encourage NGOs to play an intermediary role as a facilitator working directly with farmers.
4. Decentralize decision-making to minimize communication time, allowing quick response to problems. Allow 'point' Ministry people in the field to make decisions without requiring approval from headquarters in Windhoek.
5. Form special interest groups that will allow people to meet, discuss problems and share ideas.

Problem 2: Cheetah are perceived as a liability by farmers who also resent the Ministry and NGOs for their lack of response to cheetah-caused problems.
Action Steps:

1. Increase communication among all interested parties as specified above.
2. Make cheetah an asset through sustainable consumptive utilization or ecotourism.
3. Reduce response time by Ministry and NGOs to problems.
4. Centralize information on trophy hunters and game farmers/zoos/parks desiring cheetah so that farmers can contact a relevant person to eliminate his problem animal. This could be started as a private business initiative.
5. Train extension workers in effective communication and conflict resolutions.

Priority ideas/Discussion Points Made by this Working Group

1. Publicize this cheetah PHVA, including recommendations in the media and through newsletters.
2. Consider alternative farming strategies wherever possible.
   a. confine and control small calves up to 6 months of age by maintenance at the homestead or in a protected electrified camp.
   b. rely on herdsmen to maintain cattle in kraals at night when predation is severe.
   c. introduce donkeys (female with a foal) for cattle, and guard dogs for small stock.
   d. change to a more aggressive breed of cattle (i.e., introduce a Brahman bull).
   e. increase the natural prey base by putting out salt licks, constructing water points.
   f. fight bush encroachment.
   g. revise stocking rates for the carrying capacity of the land.
   h. synchronize calving period to coincide with natural prey calving.

3. Discourage farmers from shooting cheetah indiscriminately. Removing a cheetah creates a 'vacuum', which likely is to be occupied by other problem cheetah.

4. To reduce losses of game from cheetah, game farms must electrify perimeter fences. An 'information day' could be useful for demonstrating the effectiveness of electrified fences.

5. Encourage farmers to recognize the value of having cheetah on their property through farmers meetings, professional hunters, media and NGOs. Mr. J.F. Hein and NGOs will initiate this activity.
   a. increasing farmers' awareness of the importance of participating in cheetah research, including collecting samples and data. Farmers should be compensated for participating in research by the researchers provided that the cheetah is released where it was caught.
   b .promoting sustainable utilization (i.e., professional hunting of cheetah on the farmers' land). Farmers should receive almost half the trophy fee, and at least N$1000 should be donated to the Namibia Nature Foundation to be used for further research. This approach, which will be initiated by NAPHA, will allow problem animals to be shot and eliminated.
   c. promoting cheetah as a tourist attraction on conservancies.

Life History / VORTEX Modeling Working Group Report - Cheetah

Ulysses S. Seal (facilitator), Hu Berry, Olivia Forge, Laurie Marker-Kraus, Kristin Nowell

Introduction

Originally, cheetah were found from the Cape of Good Hope to the Mediterranean, throughout the Arabian Peninsula to the southern part of the former Soviet Union. Population numbers have declined from more than 100,000 in 1900 to approximately 9,000 to 12,000 today of free-ranging cheetah in Africa. Two population strongholds remain: Kenya and Tanzania in East Africa and Namibia and Botswana in southern Africa (Figure 1). The species' numbers in Namibia are estimated to have declined by approximately 50 percent in the past 10 years, leaving a population of about 2,500 animals. From 1980 to 1991 there were about 6,800 cheetah removed from the wild in Namibia according to CITES numbers (Figure 2). The number of animals removed annually declined from a peak of about 900 in 1982 and 1983 to about 200 in 1991. Of the total, 958 were live animal exports, and the remainder were shot.

Decreasing numbers are a result of a decline in the cheetah's habitat and prey base as well as conflicts with people. As humans convert more of the cheetah's habitat into farmland for livestock production, human and cheetah conflicts have emerged. Cheetah parks and reserves have led to direct competition with lions and hyenas which may take up to 50% of cheetah kills and which kill a high percentage of cheetah cubs. Rainfall also may influence cheetah cub survival through effects on prey density. Namibia is an arid to semi-arid country where rainfall is highly variable, with "droughts" being common.

As a result of predator competition in parks, most free-ranging cheetah live outside of protected areas. Surveys show that 70% of Namibian wildlife lives on farms ranging from 10,000 to 40,000 acres in size (4,050 to 16,200 hectares). Ninety-five percent of cheetah live on these private lands where prey is available, and other large predators generally are absent. Historically, the cheetah has been viewed as a pest and a threat to the livelihood of livestock farmers, and it is legal in Namibia to shoot an animal that interferes with one's property and livelihood. Human and cheetah conflicts may become even more frequent given the projected 3.3% growth rate of Namibia’s human population which will result in a doubling of the current population of 1.4 million in only 20-25 years.

There was a 50-60 percent decline in wildlife numbers in the 1980's attributed to a variety of circumstances including severe drought. Partly as a result of the continued overstocking of livestock on rangelands, cheetah populations came into even greater conflict with farmers. During this period, 80% of one of the cheetah's main prey, the kudu, died from a rabies epidemic. Combined, these events led farmers to take strong control measures against the cheetah, for either real or imagined increased predation on domestic livestock as the wild prey base declined. By the late 1980's, the cheetah population was believed to have been reduced by more than half.

Since almost all wildlife hunted as game belongs to the landowners and has an economic value through live sale, meat production, and trophy hunting, wildlife conservation strategies are developed along with livestock and pasture management practices. Alternative farm management practices also are being introduced to protect livestock from predators.

Molecular genetic studies have shown that the cheetah lacks genetic diversity rendering it less adaptable to environmental change and challenges. The cheetah's genetic uniformity may increase susceptibility to infectious diseases and pose another threat to population viability in Namibia. Disease risks include Feline Infectious Peritonitis (FIP) and anthrax. Canine Distemper Virus (CDV) is a potential catastrophic threat if the Serengeti biotype occurs in Namibia and infects cheetah. Rabies may be a periodic threat as exposure and immunity shift through time. Feline Immunodeficiency Virus (FIV) is a potential long-term disease threat to the Namibia population. The role and effects of other viral diseases and parasites in this population are unknown.

Population Simulation Modeling

The need for and effects of intensive management strategies can be modeled to suggest which practices may be the most effective in meeting management goals. In this case, the targets are the large Namibian cheetah population on private lands and the small population in Etosha Park. The Namibian population is not isolated from the population in Botswana, despite the presence of a game fence, so that movement between the countries likely occurs (although no information on rates of emigration between the populations was available) and the genetically effective population size may need to include both populations. The demographic effects of this interchange on the population dynamics in each country will depend upon rates of migration, age and sex structure of emigrants, their mortality rates, and their incorporation as breeding members into the Namibian population.

The management goals for the Namibian population include: 1) managing for a target population size, 2) determining the number, age, and sex structure of animals that might be removed annually while maintaining a demographically stable population, 3) controlling dispersing animals, and 4) undertaking translocations when necessary.

VORTEX, a simulation modeling package written by Robert Lacy and Kim Hughes, was used as a tool to study the interaction of multiple life history and population variables treated stochastically. The purpose was to explore which demographic parameters might be most sensitive to management practices and to test the effects of possible management scenarios. The VORTEX program is a Monte Carlo simulation of the effects of deterministic forces as well as demographic, environmental, and genetic stochastic events on wildlife populations. VORTEX models population dynamics as discrete, sequential events (e.g., births, deaths, catastrophes, etc.) that occur according to defined probabilities. The probabilities of events are modeled as constants or as random variables that follow specified distributions. VORTEX simulates a population by stepping through the series of events that describe the typical life cycle of sexually reproducing, diploid organisms.

VORTEX is not intended to give absolute answers, since it is projecting stochastically the interactions of the many parameters that enter into the model and because of the random processes involved in nature. Interpretation of the output depends upon knowledge of the biology of cheetah and of the Namibian cheetah population, the conditions affecting the population, and possible changes in natural conditions, threats, and management in the future. Model output, as with any model, is limited by the input. The biological information for the cheetah population came from the studies of Laurenson et al. (1992), Caro (1994), Marker-Kraus et al. (1996), Nowell and Jackson (1996), and personnel working in the Ministry of Environment and Tourism (MET) who participated in this PHVA Workshop.

Input Parameters for Simulations

Age of First Reproduction and breeding system (3 years on farmlands for females and 5 years for males; polygynous).

VORTEX defines breeding as the time when young are born, not the age of sexual maturity. Cheetah breed year round in Namibia. First births in the wild occur when females are, on average, about 3 years of age in the farmland population or in Etosha. VORTEX uses the mean or median age of reproduction (with an estimate of variation, as discussed below) rather than the earliest age of cub production. Thus, although some female cheetah may first give birth at 2 years of age, the average age of first cub production (among the animals in Namibia) that produced young was estimated as 3 years. Similarly, whereas males may be physiologically capable of breeding at 2 to 3 years of age, social constraints may limit breeding to older animals. The degree of social constraint may vary with population density and age structure. For this model, we chose 5 years as the mean age of males at the birth of the first cubs sired. Since the cheetah mating system is polygynous, populations must become extremely small for male reproductive age to have a significant demographic effect in the model.

Cub Production (mean litter size = 3.5; percentage of all adult females annually with no cubs = 40% or 25%; sex ratio at birth = 0.500; 66% of adult males in breeding pool)

VORTEX combines number of cubs per litter, interval between litters, and the proportion of adult-age females producing cubs into a single variable called litter size. Field data on 53 cheetah litters of different ages, observed by farmers during the current dry period, yielded a mean litter size of 3.4 (162 cubs in 53 litters). The pooled records of the Cheetah Conservation Fund (CCF) on 53 litters indicate a mean litter size of 3.1, but a wide range of cub ages were included at the time of first observation. These litters would have been subject to age dependent mortality up until the time of first observation. Also, given the high rate of cub mortality 10 to 30 days postpartum, evaluation of these data for this age effect is important for estimation of actual litter size at birth. Examination of the data, with a regression upon age at time of observation, indicated a mean litter size of 3.7 for litters ranging in age from 1 week to 4 months. As noted, this still is likely to be an underestimate of the litter size at birth in the farmland population. Observed litter sizes range from 1 to 6 with a few litters of 7 to 8 cubs reported. We used a distribution of litter sizes to yield a mean of 3.5 cubs at the average age of 3 to 4 months, the time of first observation of many of the litters. Thus estimates of additional cub mortality in the first year are from ages 3 to 12 months.

The birth interval between successfully reared litters ranges from 15 months to 2 years for the females. The gestation period is about 90 days. Cheetah that lose litters usually breed again within 3 weeks (young animals may be delayed for 3 months). The calculation of demographic mean interbirth interval was made on the basis of all adult females in the population including those that failed to breed. The published field data are for breeders only so the proportion of adult females breeding each year is usually overestimated in this literature. We used estimates of 25% and 40% of the proportion of females not producing litters in a given year. The value of 25% not producing a litter appears likely to provide an upper limit for the productivity of this population under the habitat conditions and higher prey densities that occur during a wet period.

Annual variation in female reproduction is modeled in VORTEX by entering a standard deviation (SD) for the percent females producing litters of zero. Limited data are available from individual cheetah. This variation, which may be due to fluctuations in food abundance, variations in the age at which females reach sexual maturity, infertility in some animals, and random demographic variation was set at 12.5%. VORTEX determines the percent breeding each year of the simulation by sampling from a binomial distribution with the specified mean (25 or 40%) and SD (12.5%). The relative proportions of litters of 1 to 6 cubs are kept constant. The sex ratio at birth was set at 0.5 based on the assumption of equal numbers of males and females at birth and as reported for several wild cheetah populations.

Age of Senescence (12 years)

VORTEX assumes that animals can breed (at the normal rate) throughout adult life. Cheetah can live more than 15 years, but reproduction appears to cease by age 10 to 11 in the wild, and few animals live beyond this age in the Namibian population. We used 12 years as the maximum age in the model. One effect of maximum age in the deterministic model is an increase in generation time with increasing life expectancy, since the maximum possible age of reproduction will be extended.

Mortality (3 months to 1 year of age= 46% for cubs; >1 year = 5 to 30% for females and 5 to 50% for males)

Mortalities can be entered in VORTEX in four ways: 1) as the percentage of animals in each sex-age class expected to die each year, with a corresponding variance; 2) as a fixed number removed (e.g., harvested) in each sex-age class; 3) as a catastrophic event that reduces the normal survival rate by some fixed amount, and 4) when K (carrying capacity) is exceeded, all age classes are proportionally reduced to truncate the population to the value set for K.

Cub survival (0 to 1-year age class) is highly variable among wild felid populations. Additionally, the factors affecting this variability may differ in importance among populations and at different times in the same population. Factors that have been identified in cheetah include changes in prey availability, diseases (recent anthrax outbreak in the Etosha population; see veterinary section for this and other risks), predation (lions and hyenas, which are not a significant factor in the farmland population), and possibly inbreeding depression (as described in the captive population). A cub mortality estimate of 46% was used in these model scenarios on the basis of CCF data on the decline in mean litter sizes between 3 months and 10-14 month old animals. Reported first year mortalities in other populations have ranged up to 95% with heavy lion predation on cheetah cubs.

Survival of subadult (1 to 3 years for females and 1 to 5 years for males) and adult (3 years and older for females and 5 years or older for males) cheetah in Namibia is strongly related to human influences, especially hunting and killing of nuisance cheetah on private lands. Data on the number of animals reported killed and exported (Figure 2) have been collected by government agencies and tabulated in CITES reports (Marker-Kraus et al. 1996). The natural mortality rate may range from 5 to 10% but total annual mortality could range up to 30% with removals on the farmlands. There is a bias favoring removal of males (perhaps subadult animals) based upon the capture methods and the inclination of groups of males to repeatedly use favored tree sites.

Data have been collected on individual cheetah mortality as part of a radiotelemetry and tagging study over the past 3 years (Kraus, 1996 personal communication). Twenty-six animals, 18 males and 8 females, have been monitored. The following data were useful in making preliminary estimates of crude mortality rates.

Statistic	Males	Females
Number	18	8
Total animal months	248	62
Mean (months)	13.8	7.8
Standard Deviation	9.6	5.7
Range (months)	3-32	3-19
Number dead	8	1
Mean ages (months)	64.8	56.1

Calculations of crude annual death rates were 38.6% for the males and 19.2% for the females. Four of the males were shot.

We modeled the effects of equal sex mortality and of differential greater mortality rates for males of 1.5 and 2.0 times the specified mortality rate of females. It is estimated (informed guesses) that currently about 250 animals per year are being killed or live-trapped, about 10% of the estimated population, each year. We examined the effects of mortality rates ranging from 5 to 30% for females and 5 to 50% for males. One effect of selective male mortality on the population may be to reduce the breeding pool of males and the genetically effective population size.

Catastrophes (One or two events with a 5% frequency or one event with a 10% frequency and each event with either no effect or a 20% decrease in reproduction and with either a 20%, 35%, or 50% decrease in survival).

Catastrophes are singular events outside the bounds of normal environmental variation affecting reproduction (defined in VORTEX as recruitment of individuals into the breeding population) and survival (defined in VORTEX as mortality of adults) either singly or in combination. Examples of natural catastrophes are droughts, disease, abrupt decline in prey populations, a removal or off-take event, floods, fire, or a combination of events. Catastrophes are modeled by assigning a probability of occurrence and a severity factor ranging from 0.0 (maximum or absolute effect) to 1.0 (no effect). It is also possible to model possible positive effects of an unusually good year on reproduction by setting the severity effect greater than 1.0.

Drought combined with a disease induced decline in a prey population and increased cheetah removals by farmers occurred in the early 1980's. These events can be modeled as a catastrophic event. This type of event was estimated as occurring at a 5% frequency and having several possible severity effects on survival and reproduction. There also is concern that catastrophic disease events could impact the Namibian cheetah population, with an increased frequency over the next 100 years. This is based upon recent losses to anthrax in the Etosha Park population, the cheetah’s susceptibility to FIP documented in captivity, the recent CDV event in Serengeti lions, and other possibilities (see disease section in this report). Speculative estimates of the frequency and severity of epidemic disease in felid populations by the disease working group suggested a frequency of perhaps once in 10 (10%) or 20 (5%) years, with perhaps 20-35% of the population dying and with no effect on reproduction by the survivors. We included either a single or two catastrophes as possible events in the simulations. Effects were evaluated across a range of adult mortalities (5-30%) and differing ratios of male and female mortality (1:1, 1.5:1, 2:1). Average catastrophe frequencies of 0% (which provides a no catastrophe control), 5% (20 years), 10% (10 years), 14% (7 years), and 20% (5 years) were evaluated in sensitivity analyses. Survival severities of 0.50, 0.65, 0.80; (50%, 35% and 20% reduction in survival respectively), and 1.00 (no effect on survival which effectively is a no catastrophe event as a control comparison) were examined at each catastrophe frequency. Either no effect on reproduction or a 20% reduction in reproduction was included in the severity effects of the catastrophes.

Carrying Capacity 1,500, or 2,500 or 4,000 or 6,000 individuals. Environmental Variation (EV) of 600 (± 15% of 4000) animals was included in a series of simulations with K set at 4000. No trend in K and no function for a density dependent effect on reproduction were modeled.

The carrying capacity, 'K' defines an upper limit for the population size, above which additional mortality is imposed proportionally across the age classes to return the population to the value set for K. VORTEX uses K to impose density-dependence on survival rates. Carrying capacity may increase or decline in relation to the occurrence and duration of drought cycles and wet years. Another VORTEX module has the capability of imposing density-dependent effects on reproduction that change continuously as the population approaches K. However, since data are not available to evaluate these density dependent effects in cheetah, we elected not to include these density dependent effects in these models.

We used values of K over the range of 1,500 to 6,000 to span the range of possible values for the dry and wet cycles for Namibian farmlands and to encompass the Botswana population when set at 6,000. The value of 2,500 was examined as a possible Namibian management target for population size. Also the Namibian population is thought to have been stable for several years at an estimated size of 2,500 animals. The population in Etosha National Park is estimated at about 100 animals. It is separated from the farmland population by fencing (although this may not bar exchange) and is subject to different threats. We included annual environmental variation (EV) in K in a set of simulations with K set at 4000 and SD set at 600 or 15% of K. This would provide fluctuations over the range of about 2800 to 5200 animals (±2 SD for 95% of cases in a normal distribution). No trend of change in K was tested. Environmental variation effects were included in mortality and reproduction. This range of values for K would have virtually no effect on the rates of heterozygosity loss over the 100 year time period of these projections. Also the addition of heterozygosity to the population by new mutations will be significant with populations this large (the rate of addition will increase approximately linearly with effective population size) and counterbalance the loss of heterozygosity by random drift.

Inbreeding Depression (not included in the models)

It is recognized that the cheetah population may be subject to the effects of inbreeding depression in the population already present as a result of historical events in the species. This may impact the wild population's vulnerability to disease events. These intrinsic demographic effects on reproduction and mortality are already incorporated in the estimates of mortality and reproduction in the present population used in the models. However, we did not use the option (included within VORTEX) for additional inbreeding depression effects on juvenile mortality in the future projections for the farmland cheetah models. Their relatively large population (>1,000) size will result in a low rate of heterozygosity loss by drift or randomly over the 100 year time period of these projections. Also, the model does not include the acquisition of heterozygosity with new mutations. This source of heterozygosity increases with increasing population size and will be significant, with respect to the rate of loss of heterozygosity by random drift, with populations in the thousands. Inclusion of inbreeding depression has no detectable effects in the model on the dynamics of populations of 1000 or more animals over the 100 year (about 18 - 20 cheetah generations) time span of these projections. The loss of heterozygosity over 100 years, from the start of the simulations, in populations of this size would be less than 1% of the starting level of heterozygosity or less than 0.05% per generation. This rate and magnitude of loss has no detectable additional effect on juvenile mortality or other population parameters regardless of the level of heterozygosity in the starting population or the average number of lethal equivalents (up to 10) per individual carried in the population at the start of the simulations. The model does provide and report information on the rate of loss of heterozygosity, the rate of allelic loss, and the rate of inbreeding under each scenario. There is no known way to estimate inbreeding depression effects on fitness from measured levels of molecular heterozygosity (DNA, RNA, or protein) for which there are no control comparisons.

Starting Age Distribution (stable).

We initialized the model runs with a stable age distribution, which distributes the total population among the sex-age classes in accordance with the specified mortality and reproductive schedules in the scenario, using a deterministic Leslie Matrix algorithm. Deterministic values for population growth rate, generation time, adult sex ratio, and age structure are calculated and reported in the output.

Starting Population Size (1,500 to 6,000)

We used starting population sizes of 1,500, 2,500, 4,000 and 6,000 cheetah representing the range of possible population sizes in dry and wet years and considering the Namibian population alone or connected with that in Botswana.

Iterations and Years of Projection (100 years and 200 repetitions).

Each scenario was repeated 200 times, and projections were made for the next 100 years. Output results were summarized at 10-year intervals as used in the time series figures. Each scenario tabulated in the tables has a corresponding file number for reference and retrieval of other results, if needed. The simulations were run using VORTEX versions 7.1 and 7.2 dated January or May 1996. Comparisons may be made across the data tables of files with the same file number (but a different letter prefix) whose parameter values are the same except for the specific parameters being tested and reported in that table.

Sample Input File

A sample input file used to initialize the model for one of the base scenarios for the farmland cheetah population is included at the end of this section (Table 1). The information input for each request and the question are shown in the order in which they appear in the program.

Results

Deterministic Results

We list the stochastic 'r' values for each scenario in the tables. The stochastic r values are usually lower, but never higher, than the deterministic r values, which are not reported here. Deterministic outputs in each scenario included values for the growth rate of the population (r, lambda, and Ro), the generation times for males and females, the stable age distribution, and the adult male-to-female sex ratio (Table 2). The deterministic growth rate was calculated by a Leslie matrix algorithm. Positive values of ‘r’ are necessary for a population to survive or grow, and, in principle, a zero value characterizes a stable population. Sustained negative values inevitably lead to extinction. The deterministic growth rate is not sensitive to differences in starting population size, K, or environmental variation, but varies with level of mortality, reproductive values, and the additional mortality imposed by catastrophes. The generation times for female cheetah varied from 5.0 to 5.5 years and from 6.6 to 7.0 years for males. This value is a function of age of first reproduction, maximal breeding age, and interbirth interval. Thus, there are about 17 to 20 cheetah generations in 100 years. The male to female sex ratio of adults varied between 0.49 and 0.54 depending upon imposed male mortality rates.

Stochastic Results

Base scenario

Means (and SD for r and N), calculated over the 200 iterations at 100 years, are given for stochastic population growth rates (r stoc), probabilities of extinction (Pe), final population size (N), retention of genetic heterozygosity (Het) and mean time to extinction (Te) (Tables 3- 9, Figs. 3-14). Stochastic population growth rates and the probability of extinction are sensitive to the values and the variances entered for each of the demographic and reproductive parameters.

A first approximation for a baseline scenario was constructed with *natural mortality* of 10% in the >1 year female and male age classes with no catastrophe (Figure 3; Table 3 a, #38) and including a catastrophe of 5% frequency and 0.65 severity effect on survival and no effect on reproduction of the survivors (Table 3 a, # 032; Figure 4). The proportion of females with no litter was set at 40%, mean litter size was 3.5, starting population size (N) and carrying capacity (K) were set at 2,500, and first year mortality was 46%. The set of conditions with no catastrophe yielded an r = 0.179 and with inclusion of the 5% catastrophe yielded a projected mean stochastic 'r' of 0.156 or a population growth rate of about 17% per year. Both scenarios yielded a zero probability of extinction at 100 years, mean 100 year population size at the carrying capacity of 2500 and the loss of less than 1% of heterozygosity in 100 years. The populations, under these conditions, have the potential to double in size in 4 - 5 years, if growth is unrestrained. Alternatively, these populations might sustain the removal of 200-300 animals, of the appropriate age and sex structure, each year and still remain at the target size of 2,500 animals. The current removal rate is estimated at about 250 animals per year and the population is thought to have been stable at about 2,500 animals in recent years so this base scenario (with female mortality at 20%), (Table 3 a, #s 036 & 042 and Figures 3 & 4) may approximate current conditions.

Since this is a relatively fecund, polygynous species, the mortality rate of adult females will be a critical rate limiting factor on the population growth rate, as shall be demonstrated in latter scenarios. Since adult (breeding age) females comprise about 27% of the population, under these conditions, then the removal of adult females from the population would need to be limited to about 60 - 70 females per year as their proportional share of the 200 - 300 animals that might be removed while maintaining a stable target population.

We explored the effects on these population growth characteristics of varying the number, frequency and severity of catastrophes (Tables 3 & 4), varying adult mortality (Tables 3 - 9), varying the ratio of adult male-to-female mortality (Tables 4 - 6), varying the starting population size (Table 9), and varying carrying capacity (Table 9). Parameter values resulting in a significant probability of extinction or low or negative population growth rates or sustained reduction in population size provide an idea of the limits of the resilience of the cheetah population in response to catastrophes, conditions needed for management of a stable target population, and the rate and composition of removals that might be needed to maintain a stable population size.

Probability of Extinction

Projected 100 year probabilities of population extinctions with total adult female average annual mortality of 20% or lower were zero except in the extreme scenarios with a 20% catastrophe frequency and a reduction in survival of 50% in these catastrophes. Scenarios with 30% adult female mortality had probabilities of extinction ranging from 14% to 100% depending upon the frequency and severity of the catastrophes (Figure 5). However, if the population continues to decline at the 4 to 7% annual rate experienced until recently, there is a 50 to 100% probability of extinction in the next 100 years. The population appears to have a robust growth potential of 10 to 15% per year if it is subjected to only natural mortality. Under these conditions of no human induced mortality the population could double in size in 5 to 7 years if undisturbed. Analysis of the model outputs, from scenarios using different sets of parameter values,

Stochastic Growth Rate

Mortality effects

Population growth rates are sensitive to 'natural' mortality rates in each of the age and sex classes, to the added effects of environmental variation on mortality rates, to human-induced added mortality, and to added catastrophe-induced mortality.

With all other conditions the same as in the base scenario, a 30% adult female mortality rate resulted in a high probability of extinction, Pe = 0.48, (Table 3 a), negative population growth rate, r = -0.058, and a declining population size even with no catastrophe included in the scenario (Figure 3). Increasing the starting population size to 6,000, on the assumption that the Namibian cheetah population is closely connected to the one in Botswana and using the high end assumption of population sizes does not alter the negative growth rate or the rapid rate of population decline (Figures 5 & 6). The probability of extinction at 100 years is lower (Pe = 0.22) but the population sizes of the surviving populations are low and still in decline so that final extinction of all populations would be only a matter of time. The risk of extinction would be further increased if during this time additional catastrophes occurred. The demographic and genetic impact on the Namibian population of the connection with the Botswana population depends upon the rate of exchange between the two populations. Low rates of exchange (<0.05% per year) could sustain gene flow between the populations and keep them essentially panmictic but would not provide demographic support in a rapid decline. If one population were declining, it would tend to act as a ‘demographic sink’ for the other population and possibly contribute to its decline as well if there were a significant differential rate of movement (2 - 5% per year) from one to the other. To be demographically significant this movement would have to include females.

Interactions of adult mortality and catastrophe frequency on a scenario with a catastrophe of 0.65 severity on survival (35% increase in mortality in the year of the catastrophe) yielded a family of curves for projected stochastic population growth rate (Figure 7)(Tables 3 a & 3 b, Files 032 - 037 and B32 - B37). Results indicate that 15 to 25% average annual adult mortality is the maximum that can be sustained with a catastrophe of this severity and these frequencies. Variation of catastrophe severity (0.5, 0.65, 0.8, and 1.0) on survival at a 5% frequency indicated a proportional decline in population growth rates with an increase in severity of the catastrophe even though they occurred with only a 5% probability or at an average frequency of 5 times in 100 years (Figure 9). Similarly population size declines significantly at adult mortality rates greater than 20% per year (Figure 10) even with no catastrophe effects (severity = 1.0) included in the scenario. A 5% increase in female mortality reduces the 'r' value by 0.040 to 0.045 in the range of positive values of 'r'. An increase in catastrophe severity of 0.15, at 5% frequency, on a female mortality rate of 0.15 decreases the value of 'r' by 0.010 to 0.012.

Wide variations in male mortality rates had little effect on the growth rate of the population, as expected in a polygynous species. Data on animals killed indicate that consistently more males than females are removed from the farmland population (Marker-Kraus et al. 1996). The possible demographic impact of these selective male removals was examined by varying the ratio of the male to female mortality rates. The scenarios tested included variable female mortalities with a constant male mortality rate of 30% (Tables 4 a & 4 b; Figures 11 & 12), with the male mortalities 1.5 times the female rates as the female rates were varied from 5 to 30% (Table 5), and with male mortality rates 2.0 times the female rate (Table 6). These scenarios yielded a family of 'r' value curves identical with those observed with male rates equal to female rates (Figure 7). These results indicate that the demographic characteristics of this cheetah population are relatively insensitive to a wide variation in male mortality rates. The increase in proportional male mortality has a small effect of 0.5 to 1.0% on the retention of heterozygosity in the populations at 100 years. Thus under extreme conditions the rate of heterozygosity loss might approximately double. The magnitude of this loss would be a function of population size.

Increasing the frequency of catastrophes from 5% to 10% (Tables 3 b and 4 b), or even higher (Figures 7 & 8) as suggested in some of the disease scenarios, effectively increases the average mortality, decreased the population growth rate, produced more rapid population declines and increased the probability of extinction depending upon the mortality rate of females due to other causes. This means that progressively lower female mortality rates can be allowed at higher catastrophe probabilities if the population is to be sustained at the target levels. At a 10 year average catastrophe frequency, average annual female mortality in the range of 20 to 25% can result in declining population growth (Figures 14).

Reproduction rate effects

Reproductive rates are sensitive to age of first reproduction, mean litter size, and proportion of females with litter size = 0 each year (interbirth interval). Each of these rates is also susceptible to the effects of environmental variation.

We did not model changes in the age of first reproduction or in mean litter size. Increasing the reproductive rate by increasing the proportion of females that produce a litter each year to 75% (25% of females not producing a surviving litter from 40% not reproducing in most of the scenarios) increases the population growth rate (r) by 0.05 to 0.07 (about 5 to 7% per year) and would enable the population to sustain a higher female mortality rate under any given set of catastrophe conditions. Thus a 25 to 28% female mortality rate when the catastrophe frequency is 5% (Tables 7 & 8) would still allow the populations to survive. Interbirth interval may become shorter under optimal habitat conditions during a wet period but this is not considered likely under the prevailing dry conditions so the value of 40% of females with no litter in a given year was used in most of the scenarios.

Catastrophes

The recent CDV epidemic in the Serengeti and the concern for the vulnerability of cheetah to FIV, anthrax, and other diseases prompted modeling of potential disease catastrophes over a range of frequencies and severities (Tables 3 - 9; Figures 7, 8, 13, & 14). Simulation results indicate that the growth rate of the cheetah population is affected by catastrophes occurring at average frequencies (probabilities of occurrence) as low as 5% depending on the severity of their effects on survival and reproduction. A minimum catastrophe risk of 5% with severity effects of 0.8 on both mortality and reproduction (a 20% reduction in reproduction and in survival in the year of the event) would reduce the annual population growth rate in the base scenario with 10% natural adult mortality from about 17% to about 16% per year. This would have no detectable effect on average population size. There would be no detectable effect of such catastrophes on average population size over 100 years at total female mortalities up to 20% (natural plus human induced). A 20% reduction in population size would be restored in 2 to 5 years with average annual female mortality rates of 10 - 20%. The adverse effects of more severe catastrophes on population size and growth rate, whether due to drought or disease, could be ameliorated by reducing the rates of removals from the population or specifically by reducing the rate of killing of females while the population is recovering. It is not clear what level of mortality from a disease event would be detected with current monitoring capabilities or through reporting by the farmers.

Carrying capacity and starting population size effects

Variation in carrying capacity and the starting population size over the range of 1,500 to 6,000 had no effect on the stochastic or deterministic population growth rate (r) with or without the inclusion of catastrophe events (Table 9). There was no effect on growth rate of setting the starting population size either equal to or less than the carrying capacity. Variation of K from year to year by inclusion of an environmental variation effect also had no effect on the population growth rate (Table 9). These results are as expected since the carrying capacity simply places a limit on the allowed maximum population size by randomly removing animals proportionately across all age classes in any year when this limit is exceeded.

Population Size

Comment

Projected mean surviving population size with its standard deviation at 100 years in relation to the set carrying capacity provides an indicator of the impact of the interaction of all of the parameters and their variation on the population. Thus monitoring of population size or some average density estimate and of human induced added mortality provide a basis for management. Population models provide a tool to evaluate the monitoring information against projections and provide a basis for testing the effects of selected management options. The models are subject to continued testing and modification in the same process with collection of new data. Widely fluctuating population sizes during the time course of the simulations, as indicated by the magnitude of the standard deviation, suggest greater uncertainty about the outcome in individual populations and the need for closer monitoring of the real population. Populations may stabilize, on average, at levels below the set carrying capacity with the occurrence of catastrophes or with widely fluctuating environmental variance.

Historical observations

An estimated 6,800 cheetah were removed from the wild from 1980 to 1991 according to compiled data. During the same time period it is estimated that the cheetah population declined about 50% to about 2,500 animals. This 50% decline in the cheetah population implies an annual negative growth rate of about 4 to 7%. Since no evidence was presented for a natural catastrophe during that time or for an increase in natural mortality, it is likely that the documented rate of cheetah removal exceeded the rate of replacement of the population by reproduction and immigration. Natural mortality rates of 10% combined with an additional 20% mortality, imposed by shooting and capture for export, to yield a 30% or greater total annual female mortality rate and a comparable or greater loss of males would produce negative growth rates in the range of 4 - 7% and account for the population decline. This excess mortality could be accomplished by removal of 800 to 1000 animals per year from a population of 5-6,000 at the beginning of the decline with the absolute number removed each year declining as the population size declined. Thus the recorded rate of cheetah removal from the population (Figure 2) and the estimated magnitude of the population decline with the estimated rate negative growth rate were simulated by the scenario with a total annual female mortality rate of 30% ± 7% and without the inclusion of any catastrophe events. Reproductive rates in this scenario were the same as in the base scenario. The reproductive rates were estimated from independent data as was first year mortality. These results provide an internal consistency check on the parameter values selected for the base scenario.

Current removal rates

Using the same base scenario values for parameter values, the current population of 2,500 animals might sustain an annual removal rate of 10% of adult females and 10 - 20% of adult males per year (above the natural mortality rate of 10% and assuming no natural catastrophes during the periods of removal) and still maintain a positive growth rate. Since about 27% of the population in these scenarios is estimated to be adult females, removal of about 60 to 70 adult females per year would be the maximum annual harvest rate this population would likely be able to sustain. This rate should allow maintenance of a stable population size and a margin of positive growth potential to buffer against annual environmental variation in natural reproduction and mortality. However, the occurrence of any catastrophic events would require downward adjustment of this rate of removal until the population had regained its target size.

If female cheetah exchange (migration) with neighboring populations in Botswana is occurring then population growth rates in Namibia might be buffered from higher losses depending upon the rate and direction of migration of females. If average migration rates of 5-10% of the population are occurring then the two populations could function as a single demographic unit. Estimates of the possible rate of exchange or migration into Namibia would allow a closer estimate of the demographic reinforcement from Botswana that might occur. Much lower rates (less than 0.1% per year) are needed to provide sufficient gene flow for sustaining a panmictic population, assuming that breeding of some of the exchanged individuals occurs.

Population growth rate effects

The average surviving cheetah population size projected to 100 years, starting from 2,500 animals (with 40% ± 10% of females not producing a litter each year), declines when adult female average annual mortality is 20% or greater for all values of catastrophe severity and frequency (Tables 3- 9; Figs. 4, 6, 8, 10, 12, & 14). If no catastrophe events are included in the model, populations can sustain about 20 - 25% female mortality and maintain a positive growth rate. Addition of any catastrophes at an average frequency of 5% (once in 20 years) reduces the sustainable level of annual female mortality to less than 25%. The risk of extinction over 100 years rises rapidly when these mortality rates are exceeded. Variations of male mortality rates up to double those of female mortality rates had no effect on the population size. Thus management of adult female mortality rates is critical for managing population size through management of population growth rates. Changing management based removals in response to catastrophic population losses or declines would assist population recovery. Monitoring of animals removed from the population or killed will need to include information on the sex of the animals and general age class (cub, juvenile, adult) if these data are to be most useful for management directed at maintaining the target population size.

Carrying capacity and target population size

Increasing the population size delays the median time to extinction under any given scenario conditions. Thus larger population sizes potentially have a longer time and greater capacity to recover from periods of increased mortality whether due to climatic factors, loss of prey, reduction in carrying capacity, or human induced mortality. Retention of heterozygosity and accumulation of new heterozygosity by mutation through time are also functions of population size as a determinant of effective population size. Each of these factors needs to be considered when selecting the target population size for management.

Retention of Heterozygosity

There was 1% or less loss of heterozygosity over 100 years in the populations, ranging in size from 1,500 to 6,000, with stochastic growth rates of 2% or more (Tables 3 - 9). This reflects the fact that randomly breeding populations of these sizes and with these growth rates are sufficiently large to minimize losses due to random drift effects. This rate of heterozygosity loss would be less than 0.05% per generation and would result in no detectable additional adverse inbreeding effects over the 100 year time span. Projected populations that did not grow or that declined in size lost 3% or more of their heterozygosity over 100 years which amounts to 0.1 to 0.3 % per generation. Heterozygosity values in these scenarios may underestimate the rate of heterozygosity loss depending upon the breeding structure of the population, the proportion of breeding males available, and the distribution of life-time reproductive success of males and females.

Summary and Recommendations

1. Manage the cheetah population on the farmlands so that 10% or less of the adult females and 20% or less of males are removed annually. For a population size of approximately 2,500 animals this would be about 60 to 70 adult females per year. This would provide a margin of safety for uncertainties in estimates of density, uncertainties in knowledge of natural female mortality rates, in female reproductive rates, in directions and rates of migration, and in estimates of fluctuations in natural mortality.

2. Removal of males needs to continue to be given preference over the removal of females in the control of problem animals in the farmland population. Population viability and growth rates are not as sensitive to male mortality rates over a wide range. Total annual adult male mortality rates of 30-35% will have no effect on population growth rates. It will be useful to further evaluate the genetic consequences of such a strategy.

3. Improve the estimates of annual female natural and especially removal mortality rates as a guide to possible population growth rate impacts and to provide management guidance on the number of removals that can be allowed and sustain a viable population.

Reporting by the farmers of removals by sex will provide a useful estimate.

4. Improve estimates of the proportion of females not producing a litter (that survives to the age of 3-4 months) each year. This estimate and estimates of cub survival (observed litter size) to the age of about 1 year can serve as an indicator of environmental variation effects on reproduction. Correlation with environmental or habitat (prey density) data may provide a useful management index.

5. Evaluate the impact of continued excess loss of adult females during the dry phase years on stability of population size and on the management target for the population.

6. Estimate the confidence limits of the methods used to estimate population density, available habitat, and calculated population size as a basis for estimating the magnitude of change and the number of years of change required to detect different rates of population change (decline or increase). For example, what effort, frequency of measurement, and measurement reliability would be required to detect the 4-7% annual decline in population size estimated to have occurred since 1980? Estimates of these parameters can be done with modeling and statistical methods using currently available data and theory. These estimates would provide a basis for the amount of effort required to monitor the status of the population, to detect changes in the population, and to allow adjustments of management.

Figure Legends:

Figure 1. General distribution map of cheetah in Namibia. There is some population fragmentation. The cheetah population in Etosha National Park, about 100 animals representing 5% of the total population, is relatively isolated from the farmland population of about 2,500 animals.

Figure 2. Estimated numbers of cheetah removed annually from Namibia by killing (circles) and for export based upon CITES data. The difference between the curves for killing and total (squares) represents the numbers exported.

Figure 3. Projected mean population sizes at 10 year intervals for 100 years for increasing rates of adult cheetah mortality with *no catastrophes* included in the simulations. There appears to be a break between 25 and 30% adult mortality rates.

Figure 4. Projected mean population sizes (N) at 10 year intervals for 100 years for increasing rates of adult cheetah mortality with a catastrophe of 5% frequency and a reduction in survival of 50%. There is an impact at all levels of adult mortality, but in the scenarios with 25 and 30% adult annual mortality rates the populations will become extinct.

Figure 5. Interaction of 30% adult female mortality and carrying capacity on projections of Pe, probability of extinction. The starting population size was set at the carrying capacity with K. One catastrophe at 5% probability of occurrence with the severity effect on survival and reproduction set at 0.8 (a 20% reduction for the year of occurence).

Figure 6. Interaction of 30% adult female mortality and carrying capacity on projections of N, mean surviving population size at 100 years. The starting population size was set at the carrying capacity with K = 1,500, 2,500, 4,000, or 6,000. The scenarios included one catastrophe at 5% probability of occurrence with the severity effect on survival and reproduction set at 0.8 (a 20% reduction).

Figure 7. Mean stochastic growth rates (r) as a function of interaction of adult annual mortality rates and frequency of a catastrophic event. The catastrophe survival severity was set at 0.65 for an increase in mortality of 35%. The five curves are, from top to bottom, for catastrophe frequencies of 0% (no catastrophe), 5% (20 years on average), 10% (10 years), 14% (7 years), and 20% (5 years), respectively.

Figure 8. Projected mean population sizes (N) at 100 years as a function of adult annual mortality rates and catastrophe frequency. Other parameter values for all scenarios are as in Figure 3.

Figure 9. Effects of increasing adult male and female annual mortality rates and increasing severity of a catastrophe on mortality (S = 1.0, 0.8, 0.65, or 0.5) at 5% frequency (every 20 years on average) on the mean stochastic growth rates (r). The proportion of females with no litter each year was set at 40%. The top curve (squares) is with no catastrophe.

Figure 10. Effects of increasing adult male and female mortality rates and increasing severity of a catastrophe at 5% frequency (every 20 years on average) on the projected mean population size at 100 years. The proportion of females with no litter each year was set at 40%. The top curve (squares) is with no catastrophe.

Figure 11. Effects of increasing adult female mean annual mortality rates, with the male annual mortality rates held constant at 30%, and increasing severity of a catastrophe on mortality at 5% frequency (every 20 years on average) on the stochastic growth rates. The proportion of females with no litter each year was set at 40%.

Figure 12. Effects of increasing adult female mean annual mortality rates with male mortality rates held constant at 30% and increasing severity on mortality of a catastrophe at 5% frequency (every 20 years on average) on the mean population size (N) at 100 years. The proportion of females with no litter each year was set at 40%.

Figure 13. Effects of increasing adult male and female mean annual mortality rates and increasing mortality severity of a catastrophe at 10% frequency (every 10 years on average) on the stochastic growth rates (r). The proportion of females with no litter each year was set at 40%.

Figure 14. Effects of increasing adult male and female mean annual mortality rates and increasing mortality severity of a catastrophe at 10% frequency (every 10 years on average) on the projected mean population size (N) at 100 years. The proportion of females with no litter each year was set at 40%.

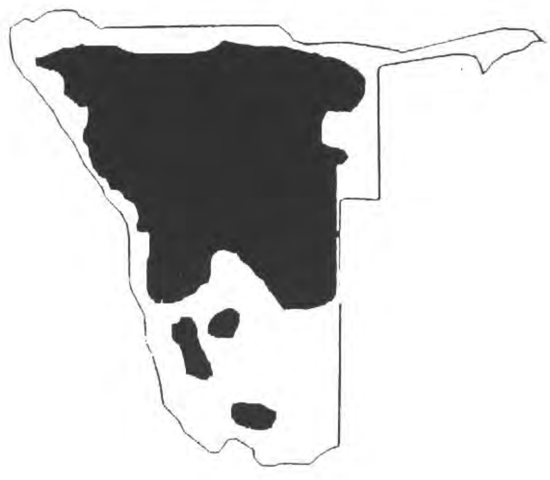

Figure 1. Generalized distribution map of cheetah in Namibia. There are no annual census data for cheetah in Namibia.

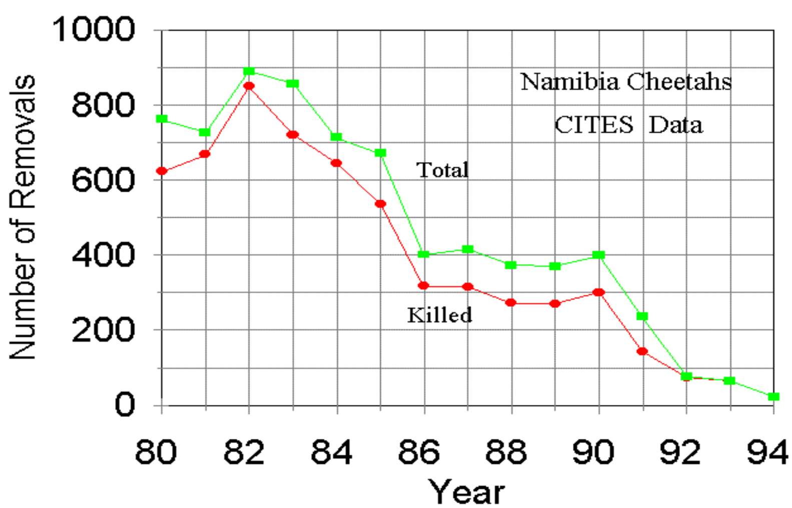

Figure 2. Numbers of cheetah killed and exported in Namibia from 1980 to 1993 based upon CITES data.

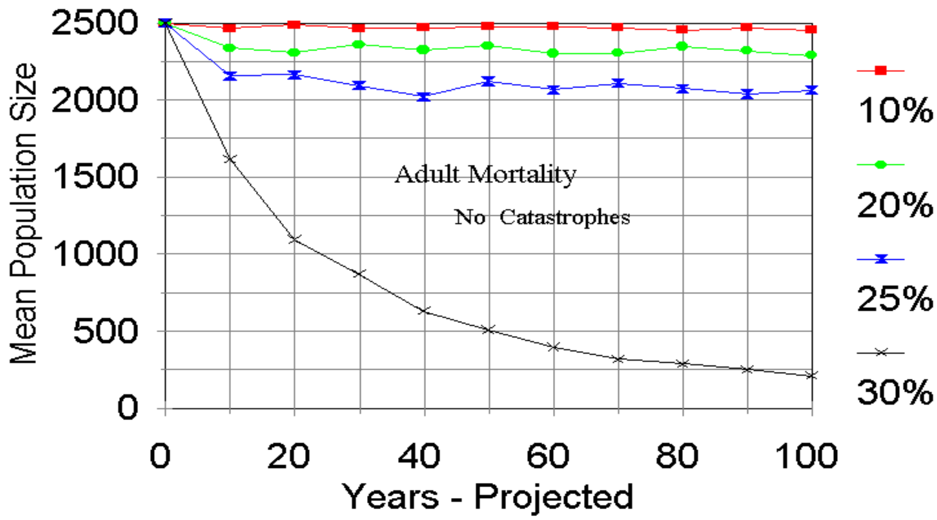

Figure 3. Effects of adult cheetah mean annual mortality (10, 20, 25, and 25%) on 'N', projected mean population size over 100 years. No catastrophes.

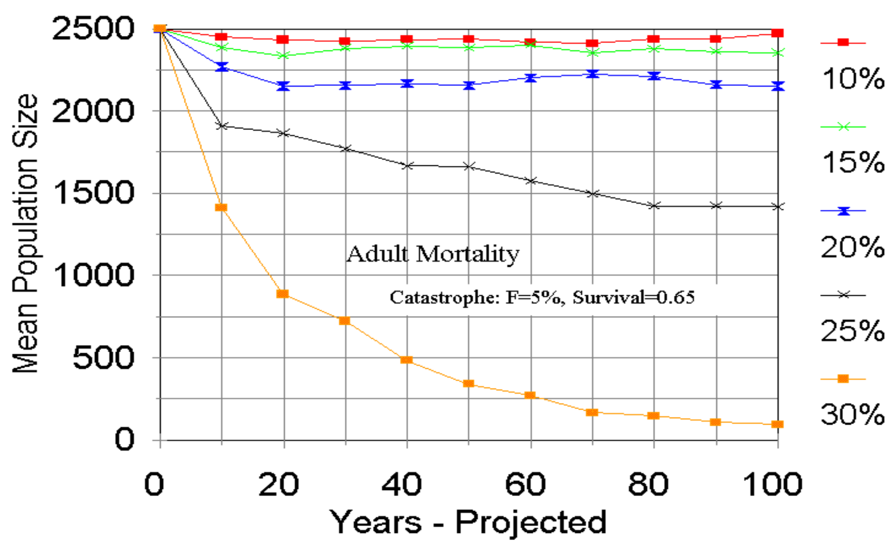

Figure 4. Effects of adult mean annual mortality (10, 20, 25, and 25%) on 'N', projected mean population size at 10 year intervals over 100 years. Catastrophe frequency of 5% (20 years) with 50% reduction in survival.

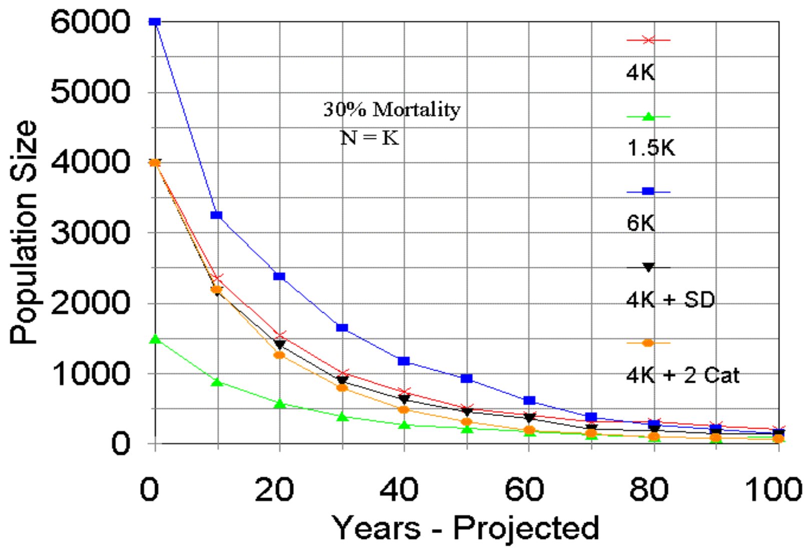

Figure 5. Interaction of 30% adult female mortality and carrying capacity on projections of Pe, probability of extinction. The starting population size was set at the carrying capacity with K. One catastrophe at 5% probability of occurrence with the severity effect on survival and reproduction set at 0.8 (a 20% reduction for the year of occurrence).

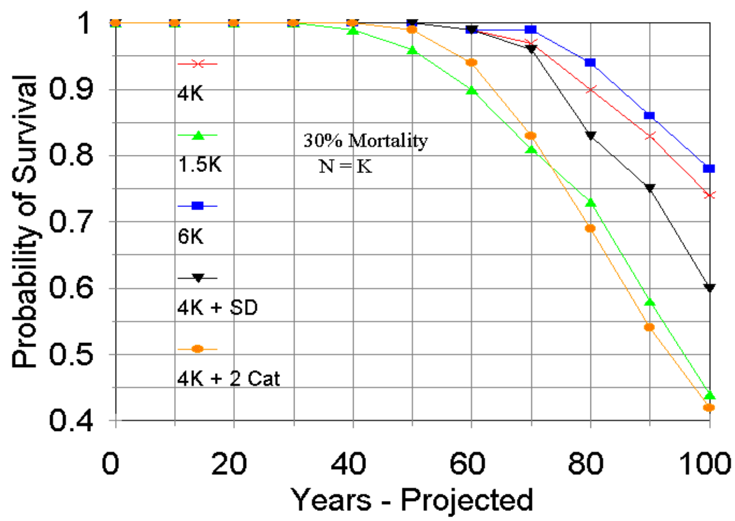

Figure 6. Interaction of 30% adult female mortality and carrying capacity on projections of N, mean surviving population size at 100 years. The starting population size was set at the carrying capacity with K = 1,500, 2,500, 4,000, or 6,000. The scenarios included one catastrophe at 5% probability of occurrence with the severity effect on survival and reproduction set at 0.8 (a 20% reduction).

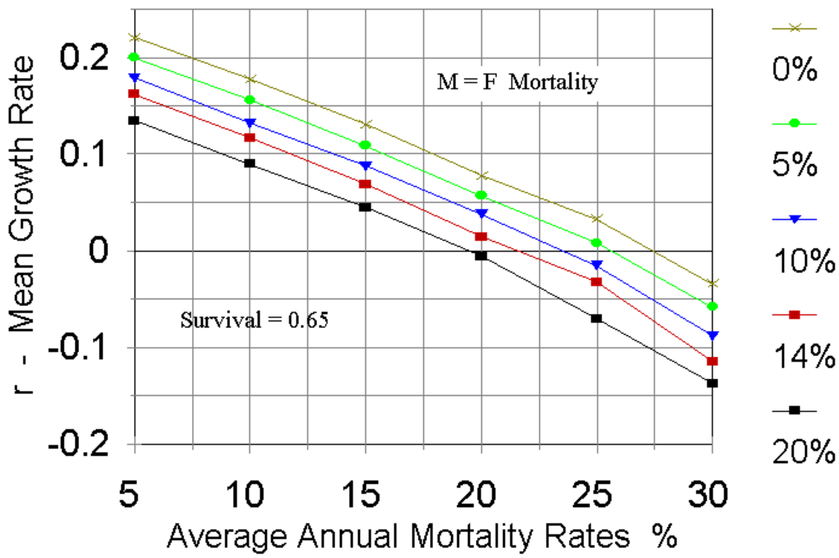

Figure 7. Interaction of adult mortality and frequency of catastrophe with a 35% increase in mortality on 'r', (mean stochastic population growth rate). Male=Female mortality. Catastrophe frequency set at 0, 5, 10, 14, or 20% (0, 20, 10, 7, or 5 years on average). Zero equals no catastrophe.

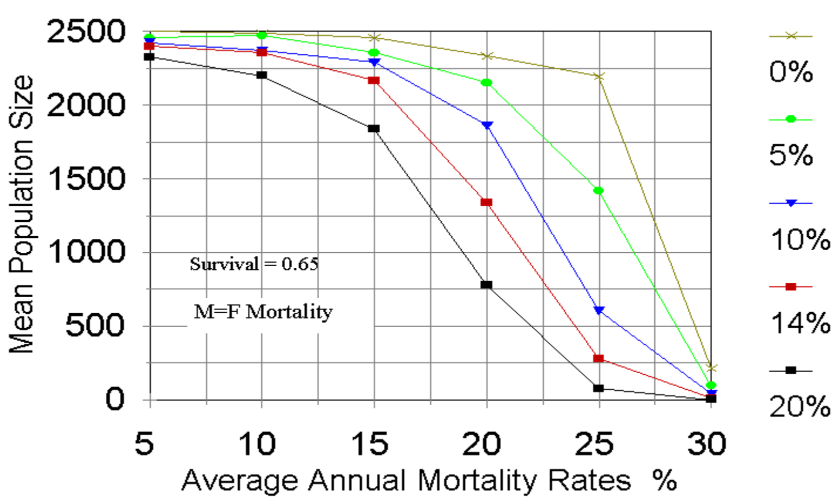

Figure 8.
Interaction of adult mortality and frequency of catastrophe with 35% increase in mortality on 'N', mean surviving population size at 100 years. Male=Female mortality. Catastrophe frequency set at 0, 5, 10, 14, or 20% (0, 20, 10, 7, or 5 years on average).

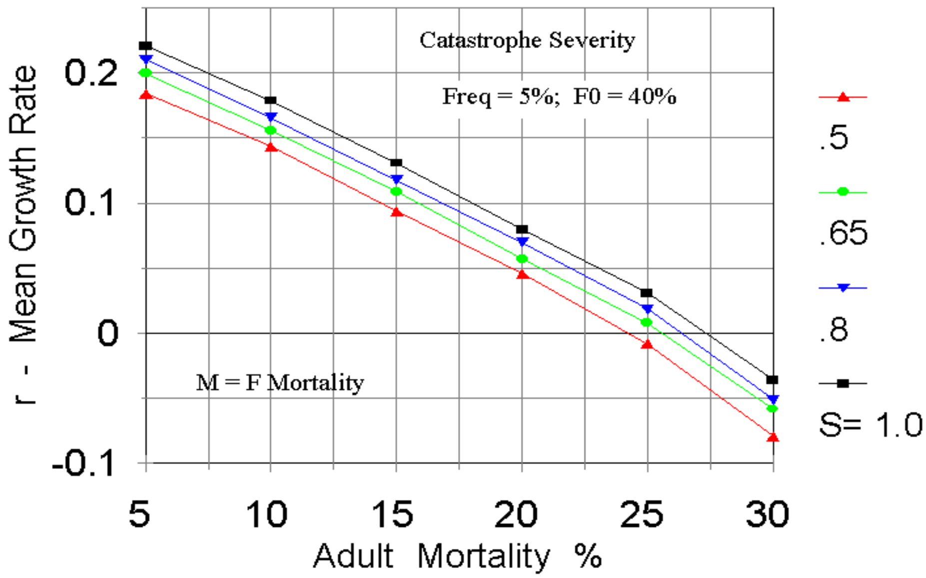

Figure 9. Interaction of increasing adult mean annual mortality (5-30%) and a catastrophe (5% frequency with 50, 35, 20 or 0% increase in mortality) on 'r' mean stochastic growth rate.

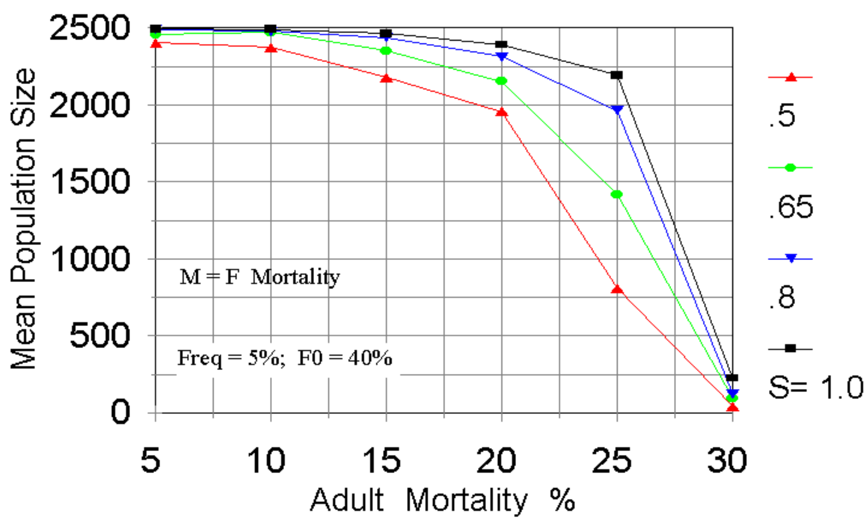

Figure 10. Interaction of increasing adult mean annual mortality (5-30%) and catastrophe (5% frequency with 50, 35, 20 or 0% increase in mortality) on 'N' the mean population size at 100 years.

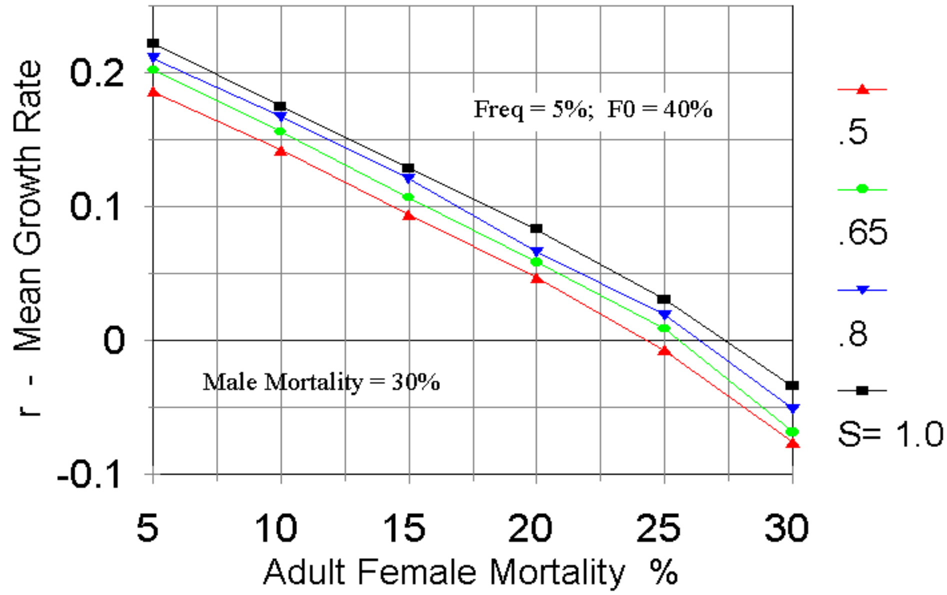

Figure 11. Interaction of increasing adult female mean annual mortality (5-30%) and catastrophe (5% frequency with 50, 35, 20 or 0% increase in mortality) on 'r', the mean stochastic growth rate. Male mortality = 30%.

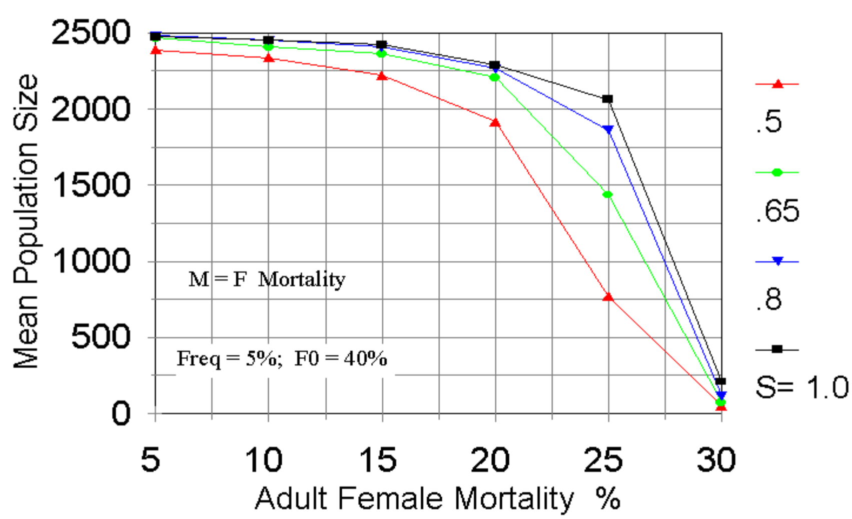

Figure 12. Interaction of increasing adult female mean annual mortality (5-30%) and catastrophe (5% frequency with 50, 35, 20 or 0% increase in mortality) on 'N', the mean population size at 100 years. Male annual mortality = 30%.

Worksl

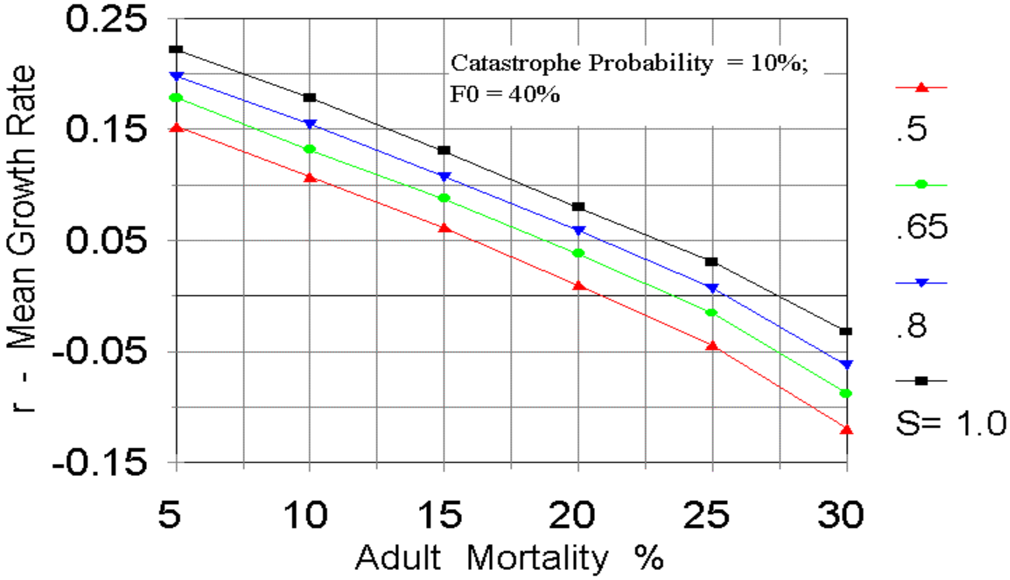

Figure 13. Interaction of increasing adult female mean annual mortality (5-30%) and catastrophe (10% frequency with 50, 35, 20 or 0% increase in mortality) on 'r' mean stochastic growth rate. Male mean annual mortality = female mortality.

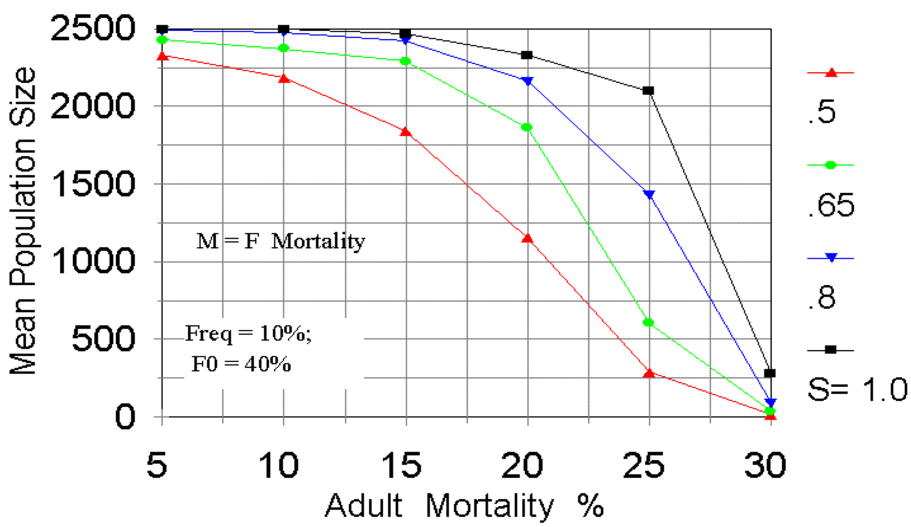

Figure 14. Interaction of increasing adult female mean annual mortality (5-30%) and catastrophe (10% frequency with 50, 35, 20 or 0% increase in mortality) on 'N', mean 100 year population size. Male mean annual mortality = female mortality.

Table 1. VORTEX input file for the base scenario.

CHEETAH.032 ***Output Filename***
Y ***Graphing Files?***
N ***Each Iteration?***
Y ***Screen display of graphs?***
100 ***Simulations***
100 ***Years***
10 ***Reporting Interval***
1 ***Populations***
N ***Inbreeding Depression?***
Y ***EV correlation?***
1 ***Types Of Catastrophes***
P ***Monogamous, Polygynous, or Hermaphroditic***
3 ***Female Breeding Age***
5 ***Male Breeding Age***
10 ***Maximum Age***
0.500000 ***Sex Ratio***
5 ***Maximum Litter Size***
N ***Density Dependent Breeding?***
40.000000 ***Population 1: Percent Litter Size 0***
0.000000 ***Population 1: Percent Litter Size 1***
0.000000 ***Population 1: Percent Litter Size 2***
30.000000 ***Population 1: Percent Litter Size 3***
30.000000 ***Population 1: Percent Litter Size 4***
0.000000 ***Population 1: Percent Litter Size 5***
12.500000 ***EV--Reproduction***
46.000000 ***Female Mortality At Age 0***
12.500000 ***EV--FemaleMortality***
10.000000 ***Female Mortality At Age 1***
3.000000 ***EV--FemaleMortality***
10.000000 ***Female Mortality At Age 2***
3.000000 ***EV--FemaleMortality***
10.000000 ***Adult Female Mortality***
3.000000 ***EV--AdultFemaleMortality***
46.000000 ***Male Mortality At Age 0***
12.500000 ***EV--MaleMortality***
10.000000 ***Male Mortality At Age 1***
3.000000 ***EV--MaleMortality***
10.000000 ***Male Mortality At Age 2***
3.000000 ***EV--MaleMortality***
10.000000 ***Male Mortality At Age 3***
3.000000 ***EV--MaleMortality***

10.000000 ***Male Mortality At Age 4***

3.000000 ***EV--MaleMortality***
10.000000 ***Adult Male Mortality***
3.000000 ***EV--AdultMaleMortality***
5.000000 ***Probability Of Catastrophe 1***
1.000000 ***Severity--Reproduction***
0.6500000 ***Severity--Survival***
N ***All Males Breeders?***
Y ***Answer--A--Known?***
66.000000 ***Percent Males In Breeding Pool***
Y ***Start At Stable Age Distribution?***
2500 ***Initial Population Size***
2500 ***K***
0.000000 ***EV--K***
N ***Trend In K?***
N ***Harvest?***
N ***Supplement?***
Y ***AnotherSimulation?***

Table 2. Partial output file for the base scenario from the input file of Table 1.

VORTEX -- simulation of genetic and demographic stochasticity
CHEETAH.032
Fri Feb 16 04:30:35 1996

1 population(s) simulated for 100 years, 100 iterations

No inbreeding depression

First age of reproduction for females: 3 for males: 5
Age of senescence (death): 10
Sex ratio at birth (proportion males): 0.50000

Population 1:

Polygynous mating;
66.00 percent of adult males in the breeding pool.

Reproduction is assumed to be density independent.

40.00 (EV = 12.65 SD) percent of adult females produce litters of size 0
0.00 percent of adult females produce litters of size 1
0.00 percent of adult females produce litters of size 2
30.00 percent of adult females produce litters of size 3
30.00 percent of adult females produce litters of size 4
0.00 percent of adult females produce litters of size 5

46.00 (EV = 12.46 SD) percent mortality of females between ages 0 and 1
10.00 (EV = 3.00 SD) percent mortality of females between ages 1 and 2
10.00 (EV = 3.00 SD) percent mortality of females between ages 2 and 3
10.00 (EV = 3.00 SD) percent annual mortality of adult females (3<=age<=10)
46.00 (EV = 12.46 SD) percent mortality of males between ages 0 and 1
10.00 (EV = 3.00 SD) percent mortality of males between ages 1 and 2
10.00 (EV = 3.00 SD) percent mortality of males between ages 2 and 3
10.00 (EV = 3.00 SD) percent mortality of males between ages 3 and 4
10.00 (EV = 3.00 SD) percent mortality of males between ages 4 and 5
10.00 (EV = 3.00 SD) percent annual mortality of adult males (5<=age<=10)
EVs may have been adjusted to closest values
possible for binomial distribution.
EV in reproduction and mortality will be correlated.

Frequency of type 1 catastrophes: 5.000 percent

with 1.000 multiplicative effect on reproduction
and 0.650 multiplicative effect on survival

Initial size of Population 1:
(set to reflect stable age distribution)

Age 1	2	3	4	5	6	7	8	9	10	Total	
324	246	185	141	106	80	61	46	35	26	1250	Males
324	246	185	141	106	80	61	46	35	26	1250	Females

Carrying capacity = 2500 (EV = 0.00 SD)

Deterministic population growth rate (based on females, with assumptions of no limitation of mates, no density dependence, and no inbreeding depression):

r = 0.156 lambda = 1.169 R0 = 2.357
Generation time for: females = 5.49 males = 6.93

Stable age distribution:

Age class	females	males
0	0.182	0.182
1	0.083	0.083
2	0.062	0.062
3	0.047	0.047
4	0.036	0.036
5	0.027	0.027
6	0.020	0.020
7	0.015	0.015
8	0.012	0.012
9	0.009	0.009
10	0.007	0.007

Ratio of adult (>= 5) males to adult (>= 3) females: 0.521

Population 1

Year 10
N[Extinct] = 0, P[E] = 0.000
N[Surviving] = 100, P[S] = 1.000
Population size = 2450.41 (15.98 SE, 159.77 SD)
Expected heterozygosity = 0.999 (0.000 SE, 0.000 SD)
Observed heterozygosity = 1.000 (0.000 SE, 0.000 SD)
Number of extant alleles = 1411.73 (8.59 SE, 85.89 SD)

Year 100
N[Extinct] = 0, P[E] = 0.000

N[Surviving] = 100, P[S] = 1.000
Population size = 2472.26 (13.25 SE, 132.48 SD)
Expected heterozygosity = 0.991 (0.000 SE, 0.001 SD)
Observed heterozygosity = 0.991 (0.000 SE, 0.002 SD)
Number of extant alleles = 209.92 (0.93 SE, 9.29 SD)

In 100 simulations of Population 1 for 100 years:
0 went extinct and 100 survived.

This gives a probability of extinction of 0.0000 (0.0000 SE),
or a probability of success of 1.0000 (0.0000 SE).

Mean final population for successful cases was 2472.26 (13.25 SE, 132.48 SD)

Age 1	2	3	4	Adults	Total	
327.64	240.67	182.14	144.09	345.00	1239.54	Males
326.95	236.12			669.65	1232.72	Females

Without harvest/supplementation, prior to carrying capacity truncation,
mean growth rate (r) was 0.1556 (0.0016 SE, 0.1636 SD)

Final expected heterozygosity was 0.9909 (0.0001 SE, 0.0008 SD)
Final observed heterozygosity was 0.9913 (0.0002 SE, 0.0022 SD)
Final number of alleles was 209.92 (0.93 SE, 9.29 SD)
****

Table 3 a. Namibian cheetah population projections - stochastic simulations.

The column headers in the tables are: **File #** = number of the VORTEX output file containing the results for this scenario; **> 1 Yr Mortal** = mean mortality rate for > 1 year age classes; **r stoc** = mean stochastic growth rate; **SD** = standard deviation of r; **Pe** = probability of extinction; **N** = mean population size of surviving populations at 100 years; **SD** = standard deviation of N; **Het** = mean heterozygosity of surviving populations at 100 years; and **Te** = mean time to extinction at 100 years.

Interaction of varying >1 year old female and male mortality from 5 to 30% and varying catastrophe survival rates on population growth rate, size, and risk of extinction. The frequency of the *catastrophe was set at 5%* (20 year average interval) with survival rate varied from 50% to 80% and with no effect on reproduction. The frequency of catastrophe is varied in Tables 1a and 1b to approximate 20, 10, 7, and 5 year average intervals.

Base scenario conditions: The age of first reproduction was set at 3 years for females and 5 years for males. Other constant parameters were: 40% of females producing no litter each year, mean litter size of 3.5, 46% 0-1 year mortality, starting population size N = 2,500, K = 2,500, 66% of males in the breeding pool, no trend in K, no density dependence of reproduction, and sex ratio at birth = 0.5. No harvests or supplementation were included. The simulations were run for 100 years with 200 repetitions.

File #	**>1 Yr Mortal**	**r stoc**	**SD**	**Pe**	**N**	**SD**	**Het**	**Te**
Catastrophe 5%: Survival = 0.500; Variable >1 year Γ & E mortality rates.								
025	5%	0.184	0.199	0.000	2405	269	99.09	0.0
020	10	0.144	0.202	0.000	2378	325	99.03	0.0
022	15	0.094	0.213	0.000	2181	463	98.91	0.0
024	20	0.046	0.219	0.000	1957	653	98.39	0.0
021	25	-0.008	0.218	0.050	810	725	94.49	75.0
023	30	-0.079	0.280	0.740	43	54	76.66	72.2
Catastrophe 5%: Survival = 0.650; Variable >1 year Γ & E mortality rates.								
037	5%	0.200	0.155	0.000	2457	157	99.14	0.0
032	10	0.156	0.164	0.000	2472	132	99.09	0.0

File #	>1 Yr Mortal	r stoc	SD	Pe	N	SD	Het	Te
034	15	0.109	0.173	0.000	2355	263	99.03	0.0
036	20	0.057	0.181	0.000	2153	434	98.91	0.0
033	25	0.008	0.178	0.010	1418	769	97.72	94.0
035	30	-0.058	0.237	0.480	96	134	83.31	77.3
Catastrophe 5%: Survival = 0.800; Variable >1 year Γ & E mortality rates.								
031	5%	0.211	0.134	0.000	2492	46	99.14	0.0
026	10	0.166	0.142	0.000	2478	88	99.11	0.0
028	15	0.118	0.152	0.000	2440	131	99.06	0.0
030	20	0.070	0.166	0.000	2316	246	98.98	0.0
027	25	0.019	0.156	0.000	1966	498	98.60	0.0
029	30	-0.051	0.221	0.360	125	163	82.38	81.2
No Catastrophe: Variable >1 year Γ & E mortality rates.								
043	5%	0.221	0.125	0.000	2497	26	99.14	0.0
038	10	0.179	0.136	0.000	2492	38	99.12	0.0
040	15	0.131	0.145	0.000	2466	106	99.09	0.0
042	20	0.080	0.157	0.000	2392	177	99.00	0.0
039	25	0.031	0.149	0.000	2196	344	98.82	0.0
041	30	-0.036	0.201	0.140	226	297	86.82	84.3

Table 3 b. Namibian cheetah population projections - stochastic simulations. Interaction of varying >1 year old female and male mortality, a *catastrophe frequency of 10%* and varying catastrophe survival rates on population growth rate, size, and risk of extinction. The frequency of the catastrophe was set at 10% with survival rate varied from 50% to 80% and with no effect on reproduction. Other conditions are as in Table 1a.

File #	>1 Yr Mortal	r stoc	S.D.	Pe	N	S. D.	Het	Te
Catastrophe 10%: Survival = 0.500; Variable >1 year Γ & E mortality rates.								
B25	5%	0.153	0.242	0.000	2329	376	99.02	0.0
B20	10	0.108	0.248	0.000	2185	524	98.85	0.0
B22	15	0.062	0.254	0.000	1840	671	98.39	0.0
B24	20	0.010	0.263	0.030	1154	892	95.28	77.0
B21	25	-0.044	0.274	0.360	290	391	87.47	77.5
B23	30	-0.119	0.328	0.950	17	20	64.02	57.1
Catastrophe 10%: Survival = 0.650; Variable >1 year Γ & E mortality rates.								
B37	5%	0.179	0.180	0.000	2426	193	99.10	0.0
B32	10	0.132	0.187	0.000	2371	278	99.07	0.0
B34	15	0.088	0.192	0.000	2291	389	98.95	0.0
B36	20	0.038	0.204	0.000	1863	579	98.46	0.0
B33	25	-0.015	0.205	0.030	606	627	93.66	81.0
B35	30	-0.088	0.271	0.830	40	51	76.12	70.3
Catastrophe 10%: Survival = 0.800; Variable >1 year Γ & E mortality rates.								
B31	5%	0.198	0.142	0.000	2487	55	99.15	0.0
B26	10	0.155	0.153	0.000	2476	70	99.11	0.0
B28	15	0.108	0.159	0.000	2424	145	99.05	0.0
B30	20	0.059	0.171	0.000	2161	377	98.93	0.0
B27	25	0.007	0.164	0.000	1432	672	98.07	0.0

File #	>1 Yr Mortal	r stoc	S.D.	Pe	N	S. D.	Het	Te
B29	30	-0.062	0.238	0.530	89	180	81.90	80.3

Table 4 a. Namibian cheetah population projections - stochastic simulations. Interaction of variable >1 year female mortality with a constant male mortality of 30% and a *5% frequency of catastrophe* with varying survival rates (0.50, 0.65, 0.80, 1.0) on population growth rate, size, and risk of extinction. The frequency of catastrophe is varied in Tables 2a and 2b to approximate 20, 10, 7, and 5 year average intervals.

Base scenario conditions: The age of first reproduction was set at 3 years for females and 5 years for males. Other constant parameters were: 40% of females producing no litter each year, mean litter size of 3.5, 46% 0-1 year mortality, starting population size N = 2,500, K = 2,500, 66% of males in the breeding pool, no trend in K, no density dependence of reproduction, and sex ratio at birth = 0.50. The simulations were run for 100 years with 200 repetitions. No harvests or supplementation were included. The simulations were run for 100 years with 100 repetitions.

File#	E Mort	r stoc	SD	Pe	N	SD	Het	Te
Catastrophe 5%: Survival=0.500; Variable female mortality; >1 Year Old Γ Mortality=30%.								
049	5%	0.186	0.227	0.000	2390	288	98.36	0.0
044	10	0.142	0.229	0.000	2339	314	98.41	0.0
046	15	0.094	0.235	0.000	2222	446	98.37	0.0
048	20	0.047	0.237	0.000	1918	635	98.05	0.0
045	25	-0.007	0.238	0.030	770	627	94.64	71.7
047	30	-0.076	0.279	0.730	49	54	80.83	73.6
Catastrophe 5%: Survival = 0.650; Variable female mortality; >1 Year Old Γ Mortality = 30%								
061	5%	0.202	0.194	0.000	2469	99	98.41	0.0
056	10	0.156	0.198	0.000	2410	221	98.53	0.0
058	15	0.107	0.200	0.000	2362	242	98.61	0.0
060	20	0.059	0.204	0.000	2206	356	98.58	0.0
057	25	0.009	0.200	0.000	1436	718	97.60	0.0
059	30	-0.068	0.246	0.640	75	126	84.30	78.3
Catastrophe 5%: Survival = 0.800; Variable female mortality; >1 Year Old Γ Mortality = 30%								

File#	E Mort	r stoc	SD	Pe	N	SD	Het	Te
055	5%	0.211	0.179	0.000	2481	89	98.41	0.0
050	10	0.167	0.181	0.000	2452	140	98.58	0.0
052	15	0.121	0.183	0.000	2410	169	98.67	0.0
054	20	0.066	0.188	0.000	2266	288	98.69	0.0
051	25	0.019	0.180	0.000	1862	545	98.42	0.0
053	30	-0.051	0.218	0.380	117	149	85.96	81.9
No catastrophe; Variable female mortality; >1 Year Old Γ mortality = 30%								
067	5%	0.222	0.170	0.000	2477	86	98.42	0.0
062	10	0.175	0.172	0.000	2454	119	98.58	0.0
064	15	0.129	0.178	0.000	2426	155	98.68	0.0
066	20	0.083	0.181	0.000	2289	234	98.74	0.0
063	25	0.031	0.174	0.000	2065	404	98.69	0.0
065	30	-0.034	0.199	0.100	211	309	88.64	86.1

Table 4b. Namibian cheetah population projections - stochastic simulations. Interaction of variable >1 year female mortality with a constant male mortality of 30%, *a catastrophe frequency of 10%*, and varying catastrophe survival rates on population growth rate, size, and risk of extinction. Other conditions are as in Table 2a.

File #	**_ Mort**	**r stoc**	**S.D.**	**Pe**	**N**	**S.D.**	**Het**	**Te**
Catastrophe 10%: Survival=0.500; Variable E mortality; Γ Mortality = 30%.								
B49	5%	0.158	0.266	0.000	2312	411	98.16	0.0
B44	10	0.111	0.271	0.000	2215	483	98.09	0.0
B46	15	0.059	0.277	0.000	1718	740	97.73	0.0
B48	20	0.011	0.279	0.040	1115	833	94.72	78.2
B45	25	-0.051	0.299	0.470	334	536	87.05	73.5
B47	30	-0.110	0.324	0.960	17	18	68.54	61.3
Catastrophe 10%: Survival=0.650; Variable E mortality; Γ Mortality = 30%.								
B61	5%	0.177	0.213	0.000	2416	208	98.36	0.0
B56	10	0.132	0.220	0.000	2362	274	98.45	0.0
B58	15	0.088	0.218	0.000	2231	372	98.51	0.0
B60	20	0.038	0.226	0.000	1883	615	97.99	0.0
B57	25	-0.015	0.222	0.030	600	599	92.77	89.3
B59	30	-0.087	0.273	0.820	47	57	75.73	70.1
Catastrophe 10%: Survival=0.800; Variable E mortality; Γ Mortality = 30%.								
B55	5%	0.199	0.184	0.000	2447	127	98.43	0.0
B50	10	0.156	0.187	0.000	2461	107	98.57	0.0
B52	15	0.109	0.190	0.000	2358	250	98.64	0.0
B54	20	0.060	0.194	0.000	2201	363	98.62	0.0
B51	25	0.008	0.187	0.000	1499	701	97.86	0.0
B53	30	-0.065	0.239	0.580	81	107	79.73	79.9

Table 5. Namibian cheetah population projections - stochastic simulations. Interaction of variable >1 year female mortality with a variable male mortality based upon a male to female ***removal ratio of 1.5*** and varying catastrophe survival rates on population growth rate, size, and risk of extinction. Catastrophe frequency was set at 5% with survival rates varied (0.50, 0.65, 0.80, 1.0). Age of first reproduction was set at 3 years for females and 5 years for males. Other constant parameters were as in Table 2a.

File#	Ε Mort	Γ Mort	r sto	S.D.	Pe	N	S.D.	Het	Te
Catastrophe 5%: Survival = 0.500; Γ to Ε removal ratio = 1.5									
069	15%	17.5%	0.094	0.213	0.000	2290	363	98.88	0.0
071	20	25	0.044	0.233	0.000	1829	701	98.06	0.0
068	25	32.5	-0.009	0.244	0.040	871	772	93.71	75.8
070	30	40	-0.084	0.317	0.780	74	82	77.11	68.1
Catastrophe 5%: Survival = 0.650; Γ to Ε removal ratio = 1.5									
077	15%	17.5%	0.110	0.177	0.000	2345	315	99.02	0.0
079	20	25	0.058	0.194	0.000	2093	490	98.81	0.0
076	25	32.5	0.011	0.204	0.000	1533	750	97.49	0.0
078	30	40	-0.070	0.285	0.670	103	147	78.06	75.1
Catastrophe 5%: Survival = 0.800; Γ to Ε removal ratio = 1.5									
073	15%	17.5%	0.121	0.158	0.000	2439	124	99.04	0.0
075	20	25	0.071	0.176	0.000	2284	280	98.85	0.0
072	25	32.5	0.017	0.188	0.000	1813	527	98.26	0.0
074	30	40	-0.052	0.260	0.430	179	362	79.57	80.5
No catastrophe; Γ to Ε removal ratio = 1.5									
081	15%	17.5%	0.131	0.150	0.000	2457	100	99.05	0.0
083	20	25	0.079	0.171	0.000	2333	234	98.90	0.0
080	25	32.5	0.029	0.180	0.000	2130	423	98.56	0.0
082	30	40	-0.038	0.243	0.160	158	298	83.55	85.1

Table 6. Namibian cheetah population projections - stochastic simulations. Interaction of >1 year female mortality with a variable male mortality of based upon a male to female ***removal ratio of 2.0*** and variable severity of catastrophes on population growth rate, size, and risk of extinction. Catastrophe frequency was set at 5% with survival rates varied (0.50, 0.65, 0.80, 1.0). Other constant parameters were as in Table 2a.

File#	E Mort	Γ Mort	r sto	S.D.	Pe	N	S.D.	Het	Te
Catastrophe 5%: Survival = 0.500; Γ to E removal ratio = 2.0									
085	15	20	0.095	0.221	0.000	2254	403	98.84	0.0
087	20	30	0.043	0.242	0.000	1858	707	97.77	0.0
084	25	40	-0.005	0.263	0.050	928	753	93.39	93.6
086	30	50	-0.088	0.335	0.860	110	97	74.95	63.8
Catastrophe 5%: Survival = 0.650; Γ to E removal ratio = 2.0									
093	15	20	0.109	0.184	0.000	2344	308	98.94	0.0
095	20	30	0.058	0.206	0.000	2159	422	98.53	0.0
092	25	40	0.012	0.231	0.000	1404	760	96.34	0.0
094	30	50	-0.076	0.312	0.840	106	113	81.66	73.8
Catastrophe 5%: Survival = 0.800; Γ to E removal ratio = 2.0									
089	15	20	0.119	0.165	0.000	2421	159	99.00	0.0
091	20	30	0.067	0.190	0.000	2275	293	98.70	0.0
088	25	40	0.018	0.217	0.000	1773	561	97.62	0.0
090	30	50	-0.062	0.295	0.640	191	301	76.65	75.0
No catastrophe; Γ to E removal ratio = 2.0									
097	15	20	0.131	0.157	0.000	2449	123	99.01	0.0
099	20	30	0.081	0.183	0.000	2313	295	98.74	0.0
096	25	40	0.031	0.209	0.000	1984	461	98.03	0.0
098	30	50	-0.044	0.275	0.380	253	380	82.60	78.1

Table 7. Namibian cheetah population projections - stochastic simulations. Interaction of >1 year female mortality with a variable male mortality based upon a male to female ***removal ratio of 1.5***, variable catastrophe survival, and 25% of females producing no litter each year, on population growth rate, size, and risk of extinction. Catastrophe frequency was set at 5% with survival rates varied (0.50, 0.65, 0.80, 1.0). Other constant parameters were as in Table 2a.

File#	**E Mort**	**Γ Mort**	**r sto**	**S.D.**	**Pe**	**N**	**S.D.**	**Het**	**Te**
Catastrophe 5%: Survival = 0.500; No litter=25%; Γ to E removal ratio = 1.5									
101	15	17.5	0.155	0.213	0.000	2365	369	98.85	0.0
103	20	25	0.105	0.232	0.000	2180	502	98.64	0.0
100	25	32.5	0.053	0.239	0.000	1906	693	97.98	0.0
102	30	40	-0.006	0.279	0.050	807	739	92.46	77.6
Catastrophe 5%: Survival = 0.650; No litter=25%; Γ to E removal ratio = 1.5									
109	15	17.5	0.170	0.181	0.000	2422	182	98.95	0.0
111	20	25	0.121	0.195	0.000	2376	250	98.85	0.0
108	25	32.5	0.071	0.208	0.000	2229	349	98.51	0.0
110	30	40	0.007	0.254	0.030	1270	693	95.17	81.3
Catastrophe 5%: Survival = 0.800; No litter=25%; Γ to E removal ratio = 1.5									
105	15	17.5	0.180	0.163	0.000	2462	98	98.95	0.0
107	20	25	0.132	0.181	0.000	2415	198	98.80	0.0
104	25	32.5	0.079	0.192	0.000	2316	281	98.57	0.0
106	30	40	0.023	0.233	0.000	1595	693	97.20	0.0
No catastrophe; Γ to E removal ratio = 1.5									
113	15	17.5	0.191	0.154	0.000	2475	73	98.96	0.0
115	20	25	0.142	0.171	0.000	2433	129	98.85	0.0
112	25	32.5	0.094	0.183	0.000	2410	183	98.63	0.0
114	30	40	0.032	0.227	0.000	1860	594	97.81	0.0

Table 8. Namibian cheetah population projections - stochastic simulations. Effects of 25% of females with no litter in a given year on interaction of >1 year female mortality with a variable male mortality based upon a male to female ***removal ratio of 2.0*** and variable severity of catastrophes on population growth rate, size, and risk of extinction. Catastrophe frequency was set at 5% with survival rates varied (0.50, 0.65, 0.80, 1.0). Other constant parameters were as in Table 2a.

File #	E Mort	Γ Mort	r sto	S.D.	Pe	N	S.D.	Het	Te
Catastrophe 5%: Survival = 0.500; No litter=25%; Γ to E removal ratio=2.0									
117	15	20	0.158	0.216	0.000	2333	396	98.79	0.0
119	20	30	0.105	0.239	0.000	2225	436	98.46	0.0
116	25	40	0.060	0.259	0.000	1967	658	97.54	0.0
118	30	50	-0.012	0.308	0.170	735	649	87.45	74.7
Catastrophe 5%: Survival = 0.650; No litter=25%; Γ to E removal ratio=2.0									
125	15	20	0.167	0.186	0.000	2464	118	98.89	0.0
127	20	30	0.117	0.206	0.000	2299	332	98.60	0.0
124	25	40	0.071	0.230	0.000	2175	438	97.95	0.0
126	30	50	0.008	0.273	0.010	1175	771	91.70	69.0
Catastrophe 5%: Survival = 0.800; No litter=25%; Γ to E removal ratio=2.0									
121	15	20	0.179	0.168	0.000	2446	123	98.91	0.0
123	20	30	0.129	0.192	0.000	2393	218	98.63	0.0
120	25	40	0.079	0.221	0.000	2269	309	98.09	0.0
122	30	50	0.018	0.260	0.010	1487	700	94.86	92.0
No catastrophe. No litter=25%; Γ to E removal ratio = 2.0									
129	15	20	0.190	0.161	0.000	2485	68	98.91	0.0
131	20	30	0.142	0.183	0.000	2433	142	98.64	0.0
128	25	40	0.091	0.215	0.000	2346	243	98.14	0.0
130	30	50	0.033	0.254	0.000	1832	543	96.31	0.0

Table 9. Effects of variable carrying capacity and starting population size and their interaction with a catastrophe event on 100 year projections of cheetah populations in Namibia and the interaction with a catastrophe. Simulations were done without a catastrophe and with a catastrophe at 5% probability. The catastrophe had a severity effect of 0.8 on reproduction and either 0.65 or o.8 on survival.

File ID	% Female	r stoc	SD(r)	Prob.	Population Size		Het %	Te
	Mortality			Extinc.	N	SD	Retain	Years
K=4000, N=2500, 5% Catastrophe; Surv =0.80, Repro =0.80								
CHEETA4.N73	10	0.167	0.148	0	3959	148	99.4	0
CHEETA4.073	15	0.119	0.161	0	3883	209	99.4	0
CHEETA4.075	20	0.069	0.181	0	3732	431	99.3	0
CHEETA4.072	25	0.018	0.187	0	2953	932	98.7	0
CHEETA4.074	30	-0.062	0.27	0.53	75	64	80.3	80.3
K=4000, N=2500, 5% Catastrophe; Surv =0.65, Repro =0.80								
CHEETA4.N77	10	0.151	0.17	0	3904	311	99.4	0
CHEETA4.077	15	0.107	0.184	0	3791	438	99.4	0
CHEETA4.079	20	0.057	0.2	0	3425	674	99.2	0
CHEETA4.076	25	0.009	0.209	0	2058	1218	98.2	0
CHEETA4.078	30	-0.069	0.284	0.67	136	199	81.5	78.6
K=4000, N=2500, No Catastrophe								
CHEETA4.N81	10	0.175	0.133	0	3983	74	99.5	0
CHEETA4.081	15	0.13	0.152	0	3941	166	99.4	0
CHEETA4.083	20	0.079	0.169	0	3689	417	99.3	0
CHEETA4.080	25	0.03	0.182	0	3306	711	99.0	0
CHEETA4.082	30	-0.034	0.242	0.17	332	385	87.9	84.6
K=1500, N=1500, 5% Catastrophe; Surv =0.80, Repro =0.80								
CHEETk15.N73	10	0.164	0.148	0	1494	43	98.5	0
CHEETk15.073	15	0.116	0.162	0	1459	96	98.4	0
CHEETk15.075	20	0.069	0.178	0	1359	177	98.2	0
CHEETk15.072	25	0.018	0.191	0	1051	361	97.1	0
CHEETk15.074	30	-0.057	0.273	0.52	92	147	78.1	72.1
K=1500, N=1500, 5% Catastrophe; Surv =0.65, Repro =0.80								
CHEETk15.N77	10	0.156	0.17	0	1458	119	98.5	0
CHEETk15.077	15	0.107	0.184	0	1425	145	98.4	0

File ID	% Female Mortality	r stoc	SD(r)	Prob. Extinc.	Population Size N	Population Size SD	Het % Retain	Te Years
CHEETk15.079	20	0.056	0.198	0	1282	289	97.9	0
CHEETk15.076	25	0.008	0.212	0.01	839	418	95.8	99
CHEETk15.078	30	-0.069	0.294	0.73	57	60	74.4	72.3
K=1500, N=1500, No Catastrophe								
CHEETk15.N81	10	0.175	0.134	0	1494	24	98.6	0
CHEETk15.081	15	0.13	0.154	0	1470	71	98.4	0
CHEETk15.083	20	0.079	0.171	0	1379	143	98.2	0
CHEETk15.080	25	0.031	0.183	0	1221	238	97.7	0
CHEETk15.082	30	-0.039	0.251	0.26	115	132	79.2	80.7
K=6000, N=2500; 5% Catastrophe, Surv =0.8, Repro =0.8								
CHEETk60.N73	10	0.164	0.146	0	5913	262	99.6	0
CHEETk60.073	15	0.115	0.163	0	5846	321	99.6	0
CHEETk60.075	20	0.07	0.179	0	5582	568	99.5	0
CHEETk60.072	25	0.015	0.193	0	3818	1614	99.0	0
CHEETk60.074	30	-0.058	0.262	0.46	99	130	81.8	80.8
K=6000, N=2500; 5% Catastrophe, Surv =0.65, Repro =0.8								
CHEETk60.N77	10	0.154	0.169	0	5843	507	99.6	0
CHEETk60.077	15	0.111	0.183	0	5467	909	99.6	0
CHEETk60.079	20	0.056	0.198	0	5119	1150	99.4	0
CHEETk60.076	25	0.005	0.211	0	2735	1812	98.1	0
CHEETk60.078	30	-0.065	0.283	0.53	74	83	77.7	77.8
K=6000, N=2500; No Catastrophe								
CHEETk60.N81	10	0.177	0.133	0	5981	66	99.6	0
CHEETk60.081	15	0.133	0.151	0	5893	276	99.6	0
CHEETk60.083	20	0.08	0.169	0	5662	523	99.5	0
CHEETk60.080	25	0.03	0.182	0	5033	1046	99.3	0
CHEETk60.082	30	-0.034	0.239	0.13	411	760	89.1	85.1
K=4000, N=2500; SD K = 600; 5% Catastrophe, Surv =0.8, Repro =0.8								
CHEETk20.N73	10	0.166	0.147	0	3811	571	99.4	0
CHEETk20.073	15	0.117	0.163	0	3574	603	99.3	0
CHEETk20.075	20	0.069	0.18	0	3378	652	99.2	0
CHEETk20.072	25	0.018	0.188	0	2458	939	98.7	0
CHEETk20.074	30	-0.057	0.262	0.44	116	141	78.8	79

File ID	% Female	r stoc	SD(r)	Prob.	Population Size		Het %	Te
	Mortality			Extinc.	N	SD	Retain	Years
K=4000, N=2500; SD K = 600; 5% Catastrophe, Surv =0.65, Repro =0.8								
CHEETk20.N77	10	0.154	0.171	0	3652	665	99.4	0
CHEETk20.077	15	0.108	0.183	0	3468	733	99.3	0
CHEETk20.079	20	0.057	0.196	0	3154	727	99.1	0
CHEETk20.076	25	0.009	0.211	0	1971	1067	98.2	0
CHEETk20.078	30	-0.069	0.285	0.66	117	178	78.0	75.8
K=4000, N=2500; SD K = 600; No Catastrophe								
CHEETk20.N81	10	0.178	0.134	0	3780	553	99.4	0
CHEETk20.081	15	0.132	0.153	0	3799	557	99.3	0
CHEETk20.083	20	0.08	0.168	0	3421	645	99.2	0
CHEETk20.080	25	0.03	0.183	0	3014	741	98.9	0
CHEETk20.082	30	-0.034	0.241	0.17	291	301	87.3	88.9
K=4000, N=2500; Two 5% Catastrophes, Surv =0.8, Repro =0.8								
CHEE2CAT.N73	10	0.152	0.157	0	3901	256	99.4	0
CHEE2CAT.073	15	0.103	0.172	0	3831	296	99.4	0
CHEE2CAT.075	20	0.052	0.191	0	3358	749	99.2	0
CHEE2CAT.072	25	0.005	0.201	0	1923	1171	98.1	0
CHEE2CAT.074	30	-0.076	0.281	0.71	70	82	76.4	74.3
K=4000, N=2500; Two 5% Catastrophes, Surv =0.65, Repro =0.8								
CHEE2CAT.N77	10	0.141	0.18	0	3753	540	99.4	0
CHEE2CAT.077	15	0.093	0.191	0	3736	448	99.4	0
CHEE2CAT.079	20	0.044	0.207	0	2968	998	99.1	0
CHEE2CAT.076	25	-0.008	0.221	0	1205	1093	95.3	0
CHEE2CAT.078	30	-0.087	0.301	0.84	73	115	69.8	70.8
K=4000, N=2500; No Catastrophes								
CHEE2CAT.N81	10	0.178	0.133	0	3986	67	99.4	0
CHEE2CAT.081	15	0.131	0.15	0	3944	154	99.4	0
CHEE2CAT.083	20	0.083	0.169	0	3717	408	99.3	0
CHEE2CAT.080	25	0.031	0.18	0	3360	612	99.1	0
CHEE2CAT.082	30	-0.034	0.244	0.12	260	281	87.5	84.2
N=K Runs								

File ID	% Female Mortality	r stoc	SD(r)	Prob. Extinc.	Population Size N	Population Size SD	Het % Retain	Te Years
K=4000, N=4000; 5% Catastrophe, Surv =0.8, Repro =0.8								
CHEExA4.072	25	0.017	0.189	0	2804	990	98.9	0
CHEExA4.074	30	-0.047	0.255	0.26	201	358	83.0	0
K=1500, N=1500; 5% Catastrophe, Surv =0.8, Repro =0.8								
CHEExk15.072	25	0.019	0.193	0	1119	331	97.0	0
CHEExk15.074	30	-0.057	0.275	0.56	95	133	77.4	96
K=6000, N=6000; 5% Catastrophe, Surv =0.8, Repro =0.8								
CHEExk60.072	25	0.018	0.19	0	4093	1530	99.3	0
CHEExk60.074	30	-0.049	0.253	0.22	153	175	83.8	0
K=4000, N=4000; SD = 600; 5% Catastrophe, Surv =0.8, Repro =0.8								
CHEExk20.072	25	0.018	0.193	0	2552	856	98.7	0
CHEExk20.074	30	-0.053	0.261	0.4	142	192	82.6	0
K=4000, N=4000; Two Catastrophes: 5% Catastrophes, Surv =0.8, Repro =0.8								
CHEx2CAT.072	25	0.004	0.202	0	2193	1215	98.3	0
CHEx2CAT.074	30	-0.07	0.271	0.58	69	59	79.0	93

Disease Working Group Report - Cheetahs

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Problems:

1. There was consensus that disease is a potential threat to Namibian cheetah population viability.

2. There was consensus that we lack sufficient information on disease prevalence in Namibian cheetahs to develop long-term management recommendations to minimize disease threats.

3. There was consensus that the biomedical laboratories in Namibia need additional training, equipment and supplies to conduct priority disease surveillance for cheetahs.

Defining the Diseases that are a Threat:

1. Infectious Diseases in Wild Cheetahs

Anthrax:

Anthrax is present throughout Namibia, but the threat to cheetahs depends on the concentration of susceptible prey and patterns of rainfall and drought. Anthrax has caused the death of several cheetahs in the limestone plains region of Etosha since 1993 (P. Lindeque, personal communication) and historically. Because cheetahs appear susceptible, significant mortalities could occur in regions where wild ungulate deaths from anthrax are concentrated. In Etosha, approximately half the cheetah population lives in these Anthrax areas. On Namibian farmland wild ungulates are sufficiently concentrated on 25% of the land to create an anthrax risk, whereas on 75% of the land, domestic cattle are vaccinated against anthrax. Increased game ranching will increase this threat. The threat of anthrax to cheetah populations also may increase during a wet cycle following a dry cycle when susceptible wild species and cheetahs return to the limestone plains regions of Etosha. However, the number of lion on the plains also would increase during a wet cycle and drive the cheetahs to lower anthrax risk areas.

Feline Coronavirus (FCoV):

Disease surveillance by the Cheetah Conservation Fund has revealed that 40% of healthy farmland cheetahs in several regions of the country have antibodies to FCoV. The prevalence in wild cheetahs of the clinical diseases of enteritis or feline infectious peritonitis (FIP) associated with this virus is unknown. Clinical FIP has been documented in captive Namibian cheetahs. Because coronavirus has caused serious epidemics in three captive facilities (U.S., Japan and Ireland), and because coronavirus has been isolated from a cheetah cub with ataxia during the recent upsurge of ataxia in cheetahs of Europe, this virus is considered a potential threat.

Canine Distemper Virus (CDV):

The potential for a catastrophic CDV epidemic is great if the Serengeti biotype arises in Namibia. Transmission to cheetahs most likely will occur from CDV-infected domestic dogs or susceptible wildlife.

Feline Immunodeficiency Virus (FIV):

The potential for developing a persistently FIV-infected population is great, and cheetahs may develop clinical disease if infected with the lion (or other species) biotype. Maintaining an FIV-negative population also would increase the potential economic value of Namibian cheetahs. At present, all cheetahs tested have been negative.

Rabies:

A periodic threat is anticipated because rabies is endemic in Namibia.

Feline panleukopenia virus (Parvovirus), feline herpesvirus 1, tuberculosis, feline leukemia virus, feline calicivirus, hemoparasites, ectoparasites, endoparasites, and toxoplasmosis all could cause morbidity and mortality in cheetahs. The degree of threat presently is unknown. However, disease surveillance by the Cheetah Conservation Fund has disclosed that some farmland cheetahs around the country have antibodies to parvovirus, herpesvirus, and calicivirus, indicating that these viruses are present in the region and wild cheetahs have been exposed to these pathogens.

2. Diseases of Captive Cheetahs

The three most common diseases in the captive population, veno-occlusive disease, glomerulosclerosis, and gastritis, have not been identified in wild cheetahs surveyed by the Cheetah Conservation Fund (L. Munson, personal communication). Therefore, these diseases are unlikely to affect significantly the Namibian population, which is predominantly free ranging. Optimizing the management of captive-held Namibian cheetahs to minimize stress will deter development of these three diseases.

3. Impact of Translocations and Animal Transfers on Diseases:

Transfer of animals between sites could increase pathogen transmission between captive facilities and between ecosystems. Also, common holding sites for translocating wild cheetahs will concentrate pathogens, exposing these cheetahs to unnaturally high doses which may overwhelm natural resistance. Therefore, unregulated animal movements may increase the prevalence of infectious diseases in both captive and wild populations.

What is Needed to Address the Problems:

1. Know the prevalence of infectious diseases in Namibia.

2. Know the pathogenicity of strains of infectious diseases in Namibia (e.g., FIV and CDV).

3. Train Namibian veterinarians and laboratory personnel in procedures to diagnose cheetah diseases (ante- and post-mortem).

4. Train farmers and field personnel to collect the biomaterials needed for disease monitoring (ante- and post-mortem).

5. Define the applied research projects to identify effective preventative measures.

6. Create a captive management plan to minimize disease.

7. Identify funding to meet the needs for surveillance, *in situ* training and applied research.

Immediate Action Plan Recommendations:

1. *Actions to Define Disease Threats*

a. Inform Namibian veterinarians during the Namibian Veterinary Workshop (17-18 February 1996) of the proposed disease-monitoring program for cheetahs in Namibia.

b. Determine the current exposure to FIV and anthrax in Namibian cheetahs by conducting appropriate testing on previously archived frozen serum samples.

i. FIV antibodies should be assessed in all available Namibian cheetah sera by Western blot analysis, currently the most reliable available method. The Western blot test is more sensitive and specific than the IDEXX CITE-Combo^{R} test that results in false negative and positive results. Western blot tests for FIV are by Dr. Margaret Barr (U.S.A.) and Dr. Stephen O'Brien (U.S.A.).

ii. Anthrax antibody titers should be determined to assess any preexisting immunity to anthrax in farmland cheetahs. Most Etosha cheetahs tested lack anthrax antibodies (P. Lindeque, personal communication). If no cheetahs have anthrax antibodies, then the entire population will be considered susceptible and the anthrax threat to the population will be considered greater than would be true if immune populations existed. Anthrax antibody levels can be detected by ELISA methods using an assay developed by Dr. P.C.B. Turnbull in England. The Etosha Ecological Institute can conduct the test. Testing will be restricted to selected samples from different farmland regions, because limited quantities of reagents are available.

c. Determine historic patterns of infectious diseases in predators and their prey in Namibia and of infectious diseases in domestic pets which are transmissible to cheetahs.

i. All unpublished data from Etosha, the Central Veterinary Laboratory and agricultural records should be combined with all available published reports to define the history of infectious diseases of cheetahs in Namibia. This summary will provide the basis for immediate disease control strategies.

ii. We propose completing this task during 1996 with student volunteers supervised by Namibian veterinarians.

d. Initiate prospective disease monitoring programs for Namibian cheetahs.

i. Begin collecting, banking, and evaluating biomaterials from all cheetahs that are handled or that die. Due to limited funding, the first year will focus on forming an effective network throughout Namibia to collect and store biomaterials. All available fixed tissues should be evaluated by histopathology without delay, and selected serology (e.g., for FIV, CDV, and anthrax) should be conducted. Costs for diagnostic procedures hopefully will be waived during the first year while funding sources are identified.

ii. The proposed network for biomaterials collection and storage will include veterinarians in private practice, Ministry of Environment and Tourism personnel, the Cheetah Conservation Fund, Africat, and possibly field researchers.

iii. Biomaterials recommended for collection and storage include fixed and frozen tissues, hair, whole blood, serum, plasma, blood smears, and semen.

e. Evaluate habitat and environmental factors that concentrate pathogens.

i. Determine the effect of dry/wet cycles and seasons on pathogen concentrations in the ecosystem.

ii. Determine the effects of wildlife and livestock management practices, such as the construction of artificial water holes, on the concentration of pathogenic agents.

f. After 3 years, collate all prospective and retrospective data to redefine disease threats to Namibian cheetahs.

i. Utilize these results to re-assess disease threats to Namibian cheetah populations and define new priorities for surveillance and research.

ii. Communicate results to all concerned parties. Ongoing communications should occur at meetings and through the publications of regional farmer, hunter, and veterinary associations, and in the scientific literature.

2. Actions to Identify Funding for Disease Monitoring and Applied Research

a. Submit a grant to NGOs and other private funding sources within 1 year for a comprehensive, long-term disease-monitoring project for Namibian cheetahs.

Initial costs of this program will be high due to the need for equipment (estimated at N$25,000 to 40,000) to collect, store, and evaluate biomaterials and to enhance regional laboratory capabilities through training (N$150,000). Subsequently, funding will be required only for supplies (N$5,000/year) and costs for diagnostic tests (N$155,000/year). Funds also will be needed for a Curator of Biomaterials (N$36,000) and for regional travel (N$100,000). Funds will be managed locally through the Veterinary Clinicians Forum.

b. Once disease-monitoring programs are established, then seek funding for applied research projects, such as an anthrax vaccine trial on cheetahs.

3. Actions to Standardize Disease Surveillance Programs and Preventative Measures

a. Design protocols for consistent collection and storage of biomaterials. Regional veterinarians will review protocols for feasibility within Namibia. Protocols to be used by non-veterinary personnel will include illustrations of tissues and collecting procedures. Non-veterinarians will receive instruction from veterinarians on methods of biomaterial collection. A curator of biomaterials will be designated to maintain inventories and monitor access to the biomaterial banks. Protocols for processing, labeling, and storing samples will be consistent with CBSG Genome Resource Bank recommendations.

b. Designate sites and techniques for evaluating cheetah biomaterials in Namibia. Sites will be chosen based on the abilities of existing personnel to perform the optimal tests and quality assurance from the laboratories. Considerable concern was expressed about the ability of existing laboratories in Namibia to perform these tests.

c. Create a communication network on the cheetah diseases involving all concerned parties. It was recognized that the veterinary community has a strong, pre-existing communication network for domestic animal diseases that involves veterinarians, farmers and the Ministry. This network should assist in communicating above wildlife disease threats.

d. Design protocols for translocations. The feasibility of these protocols should consider the constraints of:

i. need to immediately move animals from traps to a holding site.

ii. delay inherent in comprehensive infectious disease screening. Translocation protocols will include shipping and quarantine standards, required tests for infectious diseases and the acceptable results, vaccination and anti-parasiticide recommendations, housing standards, and minimum standards for physical examinations and medical records.

e. Design protocols for captive management. The Medical Procedures section of the Cheetah Species Survival Plan Husbandry Manual of the American Zoo and Aquariums Association should be adapted to meet specific needs of Namibian cheetahs.

f. Enhance existing vaccination programs for domestic cats and dogs in regions with cheetah populations. Supplement current rabies vaccination programs with vaccination against CDV in dogs and parvovirus, herpesvirus, and calicivirus in cats. The program should include education concerning the benefits of vaccinating pets. This should be an ongoing program that is initiated within 2 years.

g. Design an epidemic response plan for cheetahs that includes veterinarians, Ministry officials, and other concerned parties. Recommendations for the response plan include designing strategies for defining the extent of a given epidemic and containing the epidemic, designating routes of communication, devising strategies for vaccination of endangered wildlife, isolating threatened populations, and collection/banking of gametes to assist in 'insuring' populations population extinction.

h. Initiate collection and banking of infectious disease-free semen to assure against catastrophic loss of the population from disease. Semen can be managed through a regional Genome Resource Bank.

4.Immediate Actions to Conserve the Current Health Status of Namibian Cheetahs

a. Test all cheetahs that are to be moved (within or out of the country) for FIV antibodies. Any FIV-positive animal should not be translocated, and strict quarantine standards should be imposed.

b. Test all cheetahs that are to be moved within or into the country for FCoV antibodies. Cheetahs with positive titers should not be translocated between facilities.

c. Strict quarantine standards should be observed during translocations.

Models of Disease Threats to Namibian Cheetah Populations for the PHVA VORTEX Model

1. Anthrax: Based on the current anthrax mortality in free-ranging cheetahs from Etosha, current farming practices, current numbers and distribution of cheetahs in Namibia, and historic dry/wet cycles of 10 yr/5 yr, the model predicts that:

a. For Etosha, following a 10 year dry cycle, up to 25% of cheetahs living in the plains areas (50% of the population) would die and up to 10% of cheetah living where vaccinated livestock predominate (75% of the total population) would die. Total estimated losses would be 17.5% in the plains areas and 12.5% in farmlands.

2. CDV: Based on the Serengeti CDV epidemic in lion and assuming that the Serengeti CDV biotype was the infectious agent, and assuming that all cheetahs in the population lacked neutralizing antibodies to this biotype, then a 50% mortality can be predicted.

3. Rabies: Based on historical data from Etosha, a model would predict a 5 to 7% mortality every 15 to 20 years in cheetahs.

Genetics Working Group Report - Cheetahs

Stephen O'Brien, Jan Martenson (facilitators), Kristin Nowell, Tom Priesser, Joelle Wentzel

***Problems**:*

1. There is a lack of understanding of the management consequences of having small founder populations of cheetahs on game farms/reserves.

Solution/strategy: Develop practical guidelines for selecting founders of known origin and for managing small populations based on demographic simulation models.

2. Physical/health problems have been observed in free-ranging cheetahs.

   a. abnormal spermatozoal characteristics (developmental in origin)
   b. tooth/jaw anomalies
   c. kink in tail vertebrae

Are these anomalies indicative of inbreeding depression, infectious diseases, poison, or other factors? Are these factors on the increase?

Solution/strategy: Assess and recognize components of relative fitness that may reflect historic or recent inbreeding. Namibia has a special advantage for monitoring fitness parameters for two reasons:

   a. Constant supply of readily captured cheetahs due to their preference for play trees.
   b. CCF researchers are in place and actively monitor general health.
   (Note of Caution: animals with physiological problems may be more likely to become problem animals, be captured, and give a sampling bias of higher numbers of health problems than are prevalent in the actual wild population.)

Evaluation and reality: It would be useful to be able to recognize health problems which may be analogous to those associated with reduced genetic diversity in other animals (e.g., undescended testicles in the genetically compromised Florida panther). Given the field research programs currently in place in Namibia, and the amount of data gathered thus far, analysis of physical/health problems should be quite straight-forward, requiring more energy and computer time than money. Should any disorders be thought to be genetic in origin, the feline genome-mapping project in S. O'Brien's laboratory could aid in identifying the responsible gene(s).

The reality is that any genetic disorder may not be treatable other than by removing the carriers of the defective genes from the breeding population. Health problems found to be non-genetic in basis would need to be addressed according to cause (poor nutrition, poisoning, infectious disease).

3. The Namibian cheetah is a national treasure and has been and continues to be a fascinating subject for genetic research. However, there is a lack of indigenous capacity (geneticists with access to molecular biology technologies and funding) to investigate these questions.

Solution/strategy: Encouragement and sponsorship of interested Namibian students/interns to train in genetics under the guidance of experienced wildlife geneticists outside of Namibia and then return and apply their training to the study of indigenous species.

4. There exist several documented physiological traits, correlated with genetic uniformity, that may be reduced through maximizing outbreeding.

Solution/strategy:

a. Test geographically isolated populations for the extent of phylogenetic distinctiveness.
i. Candidate geographic isolates include:
A. jubatus jubatus, Southern Africa
A. jubatus raineyi, East Africa
A. jubatus hecki, West Africa
A. jubatus venaticus, Egypt
A. jubatus venaticus, Iran
ii. Obtain genetic samples from Egypt, Iran and Niger for analysis.

b. In captive settings, establish controlled matings between animals from geographically distinct populations, initially between *A. j. jubatus* and *A. j. raineyi*. Evaluate the offspring for fitness components observed in cheetahs. [This recommendation concurs with one made by the captive breeding working group.] Some data currently exist for the *jubatus* and *raineyi* subspecies (see Marker-Kraus, 1996). Captive (or wild-caught animals unsuitable for rehabilitating) from north and west African and Iranian cheetahs would be needed to complete this study.

c. There exists a proven sensitivity of the cheetah's ancestors, and possibly the current population, to demographic reduction and genetic homogenization.

Solution/strategy: Identify the cause of the historic bottleneck in order to anticipate and/or avoid a similar event in the future.

Evaluation and reality: Investigation into the cause(s) of a major cheetah population reduction(s) 10 to 20,000 years ago have thus far yielded only conjectures as to the cause. A final answer may never be possible with today's technologies.

Captive Populations
Working Group Report - Cheetahs

Jack Grisham (facilitator), Karl Ammann, Bruce Davidson, Claudia Feiss, Mike Fouraker, Cheryl Green, JoGayle Howard, Mandy Schumann, Tarren Wagener

Goal: Develop a management plan for captive populations that will include all animals held in captivity. Programs should network with the international community to enhance long-term species management, including both range countries and captive populations.

Defining the Namibian captive population: For the purpose of this document, a captive population is comprised of non-free-ranging animals that are managed on an individual basis and are not self-sufficient. There are two types of captive-held animals: (1) permanently held in captivity (i.e., pets, tourism); or (2) held temporarily before translocation. There are 50 to 80 cheetahs in Namibia held in permanent captivity. The majority of these are pets, with the remainder used for exportation and tourism. Most of these have origins as 'problem' animals. Namibia currently has minimum legislation regulating facilities that hold cheetahs.

Action Steps:

1. Current legislation and policy should be reviewed in the light of the recommendations contained within the final PHVA document. Namibia is developing an Action Plan for the Cheetah which should include the captive population. A coordinating body should be established that controls the fate of animals moving into and within captivity. This body should be responsible for the administration and approval of all permits for the capture and/or transportation of cheetahs. A basic principle should be minimal movement of animals from point of origin. All protocols should be developed and reviewed by the central, representative coordinating body, a 'commission'.

a. There need to be standards established the in law to control the handling and housing of animals moving into and within captivity, emphasizing (among others) the following factors (see Appendix VI for more details):

> Husbandry standards including, (but not limited to) enclosure size, water source, shade, enrichment (play tree, rocks, platforms, etc.), fencing type, enclosure location (close to other animals or visitors), hygiene.

Nutrition, including quantity, variety and type of feed, supplementation and feeding schedules.

Health, including infectious disease status and vaccination protocols).

Breeding guidelines, including gestation, litter size, special care, housing (maternity den) hand-raising guidelines and birth control.

b. Controlling movement of captive animals (especially those temporarily held) through a coordinating body (commission) will require:

A central organization for assimilating and coordinating supply and demand and discouraging random advertisements by international zoos and hunters.

Cooperation of international zoos and hunters (i.e., suppliers and demanders) by having fair representation on the commission.

Regional "rapid response teams" consisting of volunteers who willingly will quickly locate and collect problem animals.

Central or regional holding points for screening, quarantine, housing and permanently identifying animals while awaiting decisions on fate.

Legislation to support the powers of the central commission that ultimately should approve applications for permits to capture and export cheetahs.

2. Management goals for the captive Namibian cheetah populations are:

Develop a genome resource bank (GRB) (see Appendix V for more details).

Provide a source of animals for reintroduction/relocation, tourism, education, research, export and other highly worthwhile enterprises.

3. Within Namibia, a captive research population using East African-derived and Namibian-derived cheetahs should be established to allow selective and controlled inter-crossing between geographical isolates. Offspring should be assessed for the effects of inter-crossing on genotype, phenotype, disease resistance, survival and adaptive capabilities.

Recommendations Summary:

1. The Namibian Government should consider appointing a commission, comprised of representative parties (MET, farmers, hunters, veterinarian, NGOs, among others), in the next 6 months to examine existing regulations and then advise about promulgating new legislation deciding the appropriate handling and dispensation of cheetahs brought into captivity.

2. The Namibian government should consider implementing a cheetah policy using the information generated from this PHVA process for the ultimate purpose of creating a national cheetah management plan.

3. The Namibian government should consider establishing a central representative coordinating body within the next 12 months, whose function will be to set standards for captive cheetah management   In the interim, the government should consider establishing a program to assess the general health and disease status of the existing captive cheetah population

4. Captive Namibian cheetahs may serve as a valuable resource of genetic material for long-term conservation purposes and as a hedge against catastrophe. Therefore, a genome resource banking action plan (GRB) is recommended. Such a plan should be developed and implemented within the next 12 months.

POPULATION AND HABITAT VIABILITY ASSESSMENT FOR THE NAMIBIAN CHEETAH (*Acinonyx jubatus*) AND LION *(Panthera leo)*

11-16 February 1996
Otjiwarongo, Namibia

Workshop Report
February 1997

SECTION 3

WORKING GROUP REPORTS - LIONS

Wild Management Goals and Strategies
Working Group Report - Lion

Kallie Venzke, Daniel Kraus (facilitators), Trygve Cooper, Louis Geldenhys, Marshall Howe, Luke Hunter, Sandy Hurlbut, Peter Jackson, Jim Teer, Heiko Theis, Bernard Ziess

Problem 1: In Namibia (as in the rest of Africa) lion populations are experiencing accelerated decline, and available range is contracting. The lion population in Namibia has decreased from an estimated 700 animals in the 1980s to about 300 adults and sub-adults presently.

Goal 1: Maintain viable lion populations in Namibia.

Strategy 1. Continue to maintain the present habitat and prey base, particularly in Etosha and Kaudom.

Action Steps:

1. Communicate to the MET and the government the importance of Etosha and Kaudom for the continuing viability of lion populations.
2. Maintenance should be carried out as specified in Park Management Plans.

Strategy 2. Implement appropriate population research and monitoring programs.

Action Steps for Etosha:

1. Research. Concentrate on certain selected prides to gather demographic information.
2. Funding. Seek funds to support personnel and research equipment to carry out needed research.
3. Monitoring. Intensify the current monitoring program in the park by:
   a. appointing an individual to specifically concentrate on lion monitoring.
   b. permanently identifying as many individual animals as possible within the next year by branding.
   c. increasing communication with the bordering farming community and encouraging cooperation to assist in information gathering.
   d. training and equipping MET ranger staff to capture and translocate problem lion.
   e. involving MET rangers, researchers and the anti-poaching unit in information gathering and monitoring.

f. establishing a fund at NNF to support above research and monitoring actions.
g. assigning MET Control Warden for Etosha as being responsible for coordination of the above actions and personnel.

Action Steps for Kaudom: 1. Monitoring. Train Kaudom MET ranger staff at Etosha on specific monitoring techniques and data gathering applicable to the Kaudom ecosystem. MET Control Warden for Etosha will be responsible for coordinating the ranger staff and their monitoring activities.

Problem 2: Stock farmers on the borders of protected areas suffer depredation and complain of poorly maintained park fences and lack of interest from the MET. Significant lion numbers (1,000 reported during the past 30 years) have been lost to park populations as a result of being killed by farmers. In particular, the subadult cohort of lion populations appears to be experiencing excessive harvest which may be affecting park populations.

Goal 2: Minimize conflict on boundaries of existing protected range.

Strategy 1. Encourage alternative forms of land use in conflict areas:
Action Step: 1. The MET should encourage the establishment of conservancies on commercial farms and communal areas adjacent to parks as currently outlined in existing MET policies.

Strategy 2. Promote economic incentives for lion tolerance on private lands.
Action Step: 1. It is recommended that the existing MET Economist should investigate long-term economic incentives for tolerating lion on private lands. Recommendations should be promoted by the MET and appropriate NGOs in accordance with existing MET policies.

Strategy 3. Maintain and upgrade park boundaries.
Action Step: 1. The MET should be advised to upgrade Etosha boundary fences.

Strategy 4. Actively manage specific problem populations and groups.
Action Step: 1. Population management plans should be based on research and monitoring results of the recommended targeted groups.

Strategy 5. Train and equip MET personnel to capture and translocate lion leaving protected areas.
Action Step: 1. Funding for equipment to achieve those action steps outlined in Goal 1, Strategy 2 should be secured.

Strategy 6. Involve park neighbors in park activities.

Action Steps: 1. The messages from this PHVA workshop will be carried to farmers via farmer associations. Farmers also will receive regular updates about ongoing predator research inside and outside the parks.
2. 'Farmers Days' in the parks could greatly assist in improving communication between the MET and farmers.

Problem 3: There has been an increasing incidence of FIV recorded in African lion populations. The possibility of spread of this virus into the FIV-negative population in Etosha places this population under threat.

Goal 3: Maintain FIV-negative lion populations.

Strategy 1. Re-distribute lion to other areas, nationally and internationally.

Action Steps: 1. The MET should begin investigating the relocation of lion into other areas of Namibia.
2. Namibia should continue with the international placement of lion.

Strategy 2. Control movement of lion within Namibia and from foreign sources into Namibia.

Action Steps: 1. Policies that already are in place should be reviewed by MET personnel for effectiveness.

Strategy 3. Test all captive lion (especially privately-owned) for infectious diseases.

Action Step: 1. Testing should become MET policy.
2. Training and facilities for testing should be established in Namibia.

Strategy 4. Initiate a lion genome resource bank.

Action Steps: 1. Semen collection and banking already has begun on the Etosha lion. Due to the lack of current holding facilities, these samples are being held at the Brookfield Zoo in Chicago, Illinois (U.S.A.).
2. This program should be expanded
3. A permanent genome resource bank should be established in Namibia.

Human/Livestock Interaction with Predators, Communication, and Education Working Group Report - Lion

Kadzo Kangwana (facilitator), Helmut Ackermann, Dolly Ackermann, Piet Burger, Jochen Hein, Paul Jessen, Charles Phiri, Judy Storm

The group started by identifying problems that occur at the human/livestock interface with predators:

* Stock loss
* Poor communication skills
* Land carrying-capacity for lion
* Lack of environmental education in schools
* Lack of environmental understanding by farmers/citizens
* Incompatible farming methods
* Perceived lack of support from the Ministry of Environment & Tourism
* Conditions of sale of farms restrictive
* Anti-predator fence around Etosha ineffective
* Veterinary services approach outdated
* Lack of extension workers
* Extermination of predators by farmers
* All stock loss blamed on predators

These problems were grouped and tackled under the following headings: Stock Loss; Land Use and Farming Practices; and Communication, Education, and Changing Attitudes. Under each of these headings, the problems were described and action steps outlined.

STOCK LOSS

The Problem: Lions kill cattle of all ages. Cattle losses around Etosha seem to be concentrated in the wet seasons (November through February). Lion are, however, killed throughout the year. Cattle losses on the southern border of Etosha are in the range of 10 to 12 cattle per farmer per year per 500 head. In eastern Etosha, cattle losses are in the range of 50 to 60 cattle per farmer per year per 500 head. The reported number of lion killed by farmers adjoining Etosha is approximately 20 per year, but could be as many as 40. Livestock losses to lion also occur in Bushmanland, Caprivi, Kavango, and Damaraland.

Action Steps:

1. Fences need to be upgraded and made predator proof. This can be done by using wire mesh or electrification. There are, however, practical considerations including cost and maintenance. Means to raise funds to upgrade and maintain fencing include:
    a. Channeling some funds raised from tourism in Etosha into maintaining the fence.
    b. Encouraging donor investment.
    c. Placing a tourist bed-levy in Etosha camps.
    d. Encouraging visitors to Etosha to donate to a fence maintenance fund.

    One way to maintain the fence is encouraging the MET, farmers and Veterinary Service to work together and assign responsibilities for fence maintenance.

2. There needs to be increased incentive to tolerate lion by giving them a positive value through trophy hunting and ecotourism.

3. A central coordinating office needs to be established that will facilitate communication between the farmer with the problem animal and a hunting operator or game farmer who wants the animal.

4. Problem lion need to be captured for relocation outside the country.

LAND USE AND FARMING PRACTICES

Problem 1: The location of cattle farms close to protected areas (e.g., Etosha National Park) whose mission it is to conserve predators.

Action Step:

Change the policy so that farmers bordering these areas to have the option to convert to game farming.

Problem 2: Under current farming practices, most farmers have many breeding herds spread across the farm, which reduces protection ability and increases the probability of losing stock.

Action Step:

Breeding herds should be concentrated in one area which is more easily protected. By co-ordinating livestock breeding with natural breeding in wild ungulate populations, the predators are swamped with available prey during a narrow time window.

Problem 3: Specifications laid down by the Land Bank are out-dated. These specifications prevent “environmentally friendly” farming. For example, the Land Bank will not provide a soft loan to a farmer to combat bush encroachment using manual labor. However, a loan can be secured if the farmer wants to use herbicide to remove bush. Additionally, loans cannot be obtained for farmers wanting to establish game farming, but loans can be secured by cattle farmers.

Action Step:

Land Bank restrictions must be changed to allow flexibility.

EDUCATION

Problem 1: There is a general lack of understanding about environmental issues and conservation challenges.

Action Step:

The importance of conservation challenges, knowledge of ecology, importance of wildlife, and benefits of conserving wildlife must be stressed to the general public.

Within the schools - children:

1. Promote inclusion of environmental science in the syllabus throughout the school curriculum. This approach now is being promoted by some NGOs but the Ministries must become more involved. The subject must not be considered as a soft/easy option, but imperative to education.
2. Encourage school participation on world awareness days (e.g., water day).
3. Promote children's literature on the environment by NGOs and Ministries.
4. Promote use of nature trails and outdoor awareness camps during school holidays and the use of environmental education centers.
5. Increase the number of environmental education centers within the country. These centers need to be evenly distributed throughout Namibia.
6. Promote wildlife clubs and action groups within the schools.
7. Promote field trips to institutions such as NGO facilities, game parks, crocodile farms, or natural areas.
8. Study specific animals under the umbrella of the school syllabus.

Amongst farmers:

1. Promote the importance of lion conservation and explain the problems. This should be carried out by NGOs and Ministry of Environment and Tourism (extension workers).
2. Educate about conservation in general, emphasizing entire ecosystems and how all life

forms interact.
3. Convene information days on a specific species where farmers are invited and speeches and slideshows are given.
4. Arrange for experts to attend farmers' association meetings to speak about conservation issues, new farming practices, and other conservation-related topics.

COMMUNICATION

Problem 1: There is a lack of communication among (1) farmers and the Ministry of Environment and Tourism, (2) farmers and farmers, (3) different departments within the same Ministry, (4) ministries, (5) NGOs and Ministries, and (6) NGOs and farmers. The response time between reporting a problem and receiving assistance is excessive.

Action Steps:

1. All concerned organizations should identify a 'point' person responsible for assisting in resolving problems. Problems should be tackled within the constraints of MInistry staff shortages by allowing NGOs or other interested parties to help. The Ministry should act in a coordinating role while being flexible as to who implements problem- solving activities.
2. Encourage extension officers from the Ministry of Agriculture to visit farmers.
3. Encourage NGOs to play an intermediary role as a facilitator while working directly with farmers.
4. Decentralize decision-making to minimize communication time, allowing quick response to problems. Allow point Ministry people in the field to make decisions without requiring approval from headquarters in Windhoek.
5. Form special interest groups that will allow people to meet, discuss problems, and share ideas.

Problem 2: Lion are perceived as a liability by farmers who also resent the Ministry for their lack of response to lion-caused problems.

Action Steps:

1. Increase communication among all interested parties as specified above.
2. Make lion an asset through sustainable consumptive utilization or ecotourism.
3. Reduce response time by Ministry to problems.
4. Centralize information on trophy hunters and game farmers/zoos/parks desiring lion so that farmers can contact a relevant person to remove a problem animal. This could be started as a private business initiative.
5. Train extension workers in effective communication and conflict resolution.

Priority Ideas/Discussion Points Made by this Working Group

1. Publicize the findings of this lion PHVA.

2. Implement the following short-term strategies immediately:

    a. Identify areas with the highest stock losses. MET staff should initiate this recommendation at the next Farmers' Association meeting. Mr. Ackermann will place this item on the next agenda.
    b. Have the MET make available stock-piled fencing material at Etosha to be installed at once by either farmers or MET personnel. The warden at Etosha, Mr. K. Venzke, will initiate this action.
    c. Reinitiate communication among farmers, the MET, and the Veterinary Services. Mr. Ackermann will place this issue on the agenda for the next Farmers' association meeting. All three associations in the area will be informed.

3. Implement the following long-term strategies:

    a. Change existing legislation for stock farmers that prevents farming anything other than domestic animals. The Namibian Agricultural Union, the Ministry of Agriculture, the MET, and farmers must collaborate to achieve this goal. The NAU will initiate this activity.
    b. Secure funding for upgrading the Etosha fence, making it predator-proof. There should be communication among the MET, farmers, NGOs, and Veterinary Services on this issue. Revenue from Etosha should be used to maintain the fence. MET personnel will initiate this action.
    c. Promote environmental awareness among the public, emphasizing to farmers the importance and benefits of preserving predators. The NGOs will initiate this action. *The Natural Ecology Textbook* by J. Storm (for school grades 11 and 12) will include a chapter on predators.

Life History / VORTEX Modeling Working Group Report - Lion

Ulysses S. Seal (facilitator), Hu Berry, Olivia Forge, Laurie Marker-Kraus, Kristin Nowell

Introduction

Namibia is host to a unique and significant lion population that is seriously threatened by human conflicts, range loss, and potential disease threats. Historically, lion ranged over most of the northern half of the country and, partly, in the east, west, and south. Few historical quantitative population estimates are available, although total lion numbers were estimated at approximately 500 in 1975 and approximately 700 individuals in 1980. Since then, the Namibia lion population has been declining, and now is estimated at only 300 adult and sub-adult animals (Fig. 1 for Etosha National Park). This trend may represent a nearly 50% decline in lion numbers over the past 15 years, although cenusing techniques used in the 1970s and 1980s were less precise than those used currently, which may lend a margin of error to the above estimates. About 85% of Namibian lion currently now are restricted to two protected areas, the Etosha National Park (180 to 200 lion) and Kaudom Game Reserve (50 lion based upon the 1995 estimate; 43-65 adults in 1994). A third, smaller population in Bushmanland was estiamted to contain 11-18 adults in 1994.

Rainfall appears to be a primary determinant of lion cub survival and, therefore, of future population potential. Namibia is an arid-to-semi-arid country where rainfall is as yet unpredictable and highly variable with "droughts" being common and good rainfall years the exception. More over, at present only Etosha (22,270 km^2) and the Kaudom Game Reserve (3,840 km^2) have long-term viable lion populations. Etosha's lion are virtually isolated whilst Kaudom's lion still have interactive access to the lion of Botswana.

Threats to the Namibian lion population include conflicts with livestock, agriculture, and humans with at least 1,000 lion reported destroyed from 1965 to 1994 on farmlands bordering Etosha (Fig. 2). Such human-lion conflicts may become even more frequent given the projected 3.3% growth rate of Namibia's human population which will result in a doubling of the current population of 1.4 million in only 20 years.

Infectious diseases in wild lion are another threat to the viability of the isolated Etosha population. Canine Distemper Virus (CDV) is a potential catastrophic epidemic threat if the Serengeti biotype occurs in Namibia. Rabies may be a periodic threat as exposure and immunity shifts through time. Feline Immunodeficiency Virus (FIV) is a potential long-term disease threat to the Namibian lion populations, as all are FIV seronegative and, therefore, did not evolve with the virus (as may be the case with infected lion populations). The role and effects of parasites and other viral diseases in this population are unknown.

Population Simulation Modeling

The need for and effects of intensive management strategies can be modeled to suggest which practices may be the most effective in meeting management goals for the Etosha population including, (1) managing population size, (2) controlling dispersing animals, and (3) undertaking reintroduction or translocation programs.

VORTEX, a simulation modeling package written by Robert Lacy and Kim Hughes, was used as a tool to study the interaction of multiple life history and population variables treated stochastically. The purpose was to explore which demographic parameters might be most sensitive to management practices and to test the effects of possible management scenarios. The VORTEX program is a Monte Carlo simulation of the effects of deterministic forces as well as demographic, environmental, and genetic stochastic events on wildlife populations. VORTEX models population dynamics as discrete, sequential events (e.g., births, deaths, catastrophes, etc.) that occur according to defined probabilities. The probabilities of events are modeled as constants or as random variables that follow specified distributions. VORTEX simulates a population by stepping through the series of events that describe the typical life cycle of sexually reproducing, diploid organisms.

VORTEX is not intended to give absolute answers, since it is projecting stochastically the interactions of the many parameters which enter into the model and because of the random processes involved in nature. Interpretation of the output depends upon our knowledge of the biology of the Etosha lion population, the conditions affecting the population and possible changes in the future.

Model output of the model is limited by input. The biological information for the Etosha lion population came from the studies of Hu Berry for the years 1980-1988 (unpublished) and Stander for the years 1985-1989 (Madoqua 1991, 18:1-9). Information on the Kaudom Game Reserve and Bushland subpopulations was available from the studies of Stander (unpublished). We also used and made comparisons with published data lion from studies of the Serengeti National Park (Bertram, 1975) and Kruger National Park (Smuts et al., 1978) lion populations.

Input Parameters for Simulations

Age of First Reproduction (5 years for females and 6 for males).

VORTEX defines breeding as the time when young are born, not the age of sexual maturity. First births in the wild occur when females are about **5 years** of age in the Etosha population. VORTEX uses the mean or median age of reproduction (with an estimate of variation, as discussed below) rather than the earliest age of cub production. Thus, although some female lion may give birth at 4 years of age, the average age of first cub production among the wild animals that produced young was estimated as 5 years, so this value was used in the model.
It is likely that reproductive maturity in the wild animals may be delayed relative to captive animals or to a rapidly growing wild population. Similarly, whereas males are physiologically capable of breeding at 4 to 5 years of age, social constraints may limit breeding to older animals. The degree of social constraint may vary with population density and age structure. For this model, we chose 6 years as the mean age of males at the birth of the first cubs sired. Because the mating system in lion is polygynous, populations have to become extremely small for the choice of male reproductive age to have a significant demographic effect in the model.
Cub Production (mean litter size = 2.13 or 2.7; percentage of females annually with no cubs = 66% or 50%; sex ratio at birth = 0.5).

VORTEX combines number of cubs per litter, interval between litters, and the proportion of adult-age females producing first cubs into a single variable called litter size. Field data on Etosha lion during a 6 year dry period yielded a mean litter size of 2.13 $\pm$ 0.7 (Berry unpublished) for cubs observed at less than 1 to 2 weeks of age. Historical observations on 126 litters in Etosha, over a period including wet phase years yielded a mean litter size of 2.7 $\pm$ 1.0. A mean litter size of 2.5 (148 cubs in 59 litters) was reported for wild lion in Tanzania when litters were first observed at 4 to 6 weeks of age (Bertram, J. Zool. Lond., 1975, 177:463-482). Smuts (1978) reported a mean litter size of 3.0 for 47 litters born in Kruger National Park. About 98% of lion litters are comprised of 1 to 4 cubs. These differences at different times in Etosha and at other locations no doubt are related to the age at which the cubs are observed, nutritional status, genetics, or unobserved early mortality.

The interval between successfully reared litters ranges from 2 to 4 years for female lion. The calculation of demographic mean interbirth interval needs to be made on the basis of all adult females in the population including those not breeding during the study period. Berry observed that, over a 6-year period in Etosha, 2 females did not produce a litter, 15 females produced a single litter, and 19 litters were produced by 7 females. An overall average of 66% of females failed to produce cubs each year. This yields 3 years as the average reproductive interval for lion in the Etosha population. For the simulation models of the wild population, we used 66% as the frequency of litters of zero with 34% of females producing a mean litter size of 2.13 cubs (3% litters of one, 25% litters of two, 5% litters of 3, and 1% litters of 4 cubs). Comparisons were made with a 2 year average reproductive interval and with an average litter size of 2.7 cubs. These values appear likely to provide upper limits for the productivity of this population under the habitat conditions and higher prey densities that may occur during a wet period.

Annual variation in female reproduction is modeled in VORTEX by entering a standard deviation (SD) for the percent females producing litters of zero. Data were available from individual lion in the Etosha study. This variation, which may be due to fluctuations in food abundance, variations in the age at which females reach sexual maturity, and infertility in some animals, was set at 16%. VORTEX determines the percent breeding each year of the simulation by sampling from a binomial distribution with the specified mean (66%) and SD (16%). The relative proportions of litters of 1, 2, 3, and 4 cubs are kept constant. The sex ratio at birth was set at 0.5 based on the assumption of equal numbers of males and females at birth, as has been reported for several wild lion populations.

Age of Senescence (14 years)

VORTEX assumes that animals can breed (at the normal rate) throughout adult life. Lion can live more than 15 years, but reproduction appears to cease by age 12 to 14 in the wild and few animals live beyond this age in the Etosha population. We examined the effects of setting 12 and 14 years as the maximum age in the model. One effect is an increase in generation time with increasing life expectancy, since the maximum possible age of reproduction will be extended.

Mortality (0 to 1 year of age = 54% from birth; >2 year = 7% for females and 9.8% for males)

Mortalities can be entered in VORTEX in three ways: 1) as the percentage of animals in each sex-age class expected to die each year, with a corresponding variance; 2) as a fixed number removed (e.g., harvested) in each sex-age class; and 3) as a catastrophic event that reduces or increases the normal survival rate by some fixed amount. When K (carrying capacity) is exceeded, all age classes are proportionally reduced to truncate the population to the value set for K.

Cub survival (0-1 year age class) is highly variable among wild felid populations. Additionally, the factors affecting this variability may differ in importance among populations and at different times in the same population. Factors that have been identified in lion include pride takeover by male groups (which does not appear to occur in Etosha), changes in prey populations, diseases, and predation on lion cubs (leopards and baboons). Mortality estimates were made on the basis of direct observations of the survival to 1 year of the 70 cubs born in 32 litters over a 6 year period in the Etosha population (Berry, unpublished data). There were 70 cubs observed (34 females, 31 males, 5 unknown) and 32 cubs (12 females, 20 males) that survived to 1 year of age for a survival rate of 46%. We examined scenarios with 0 to 1 year mortality rates ranging from 15% to 75% for male and female cubs. This range of values encompassed those reported for lion cubs in this age span under different conditions and tested the sensitivity of the population dynamics to changes in this parameter.

Survival of subadult and adult wild lion in Namibia is strongly related to human influences, including hunting and killing of nuisance lion on private lands. About half the observed adult lion deaths by Berry were the result of human actions. About 40% of the lion killed were subadult males. Berry followed 36 adult females for 6 years and observed 15 mortalities of which 8 were due to human intervention. The combined average annual mortality rate was 7%, and this value was used in the base scenarios. Rates of 4%, 10%, and 13% also were modeled as part of the sensitivity analyses and to evaluate the effect of eliminating or increasing the rate of human-induced mortality. Berry followed 22 adult males during the same period and observed a total mortality of 13 animals for an average annual mortality rate of 9.8%, again with half due to unnatural causes. The number of subadult males killed (averages 8 per year) was 2 to 3 fold greater than that for adult males and may be 15-20% of this age class per year. There may be a genetic impact on the effective population size produced by this selective mortality of young males.

Catastrophes (Four, 3 negative and 1 positive).

Catastrophes are singular events outside the bounds of normal environmental variation affecting reproduction (defined in VORTEX as recruitment of individuals into the breeding population) and survival (defined in VORTEX as mortality of adults) either singly or in combination. Natural catastrophes can most likely be droughts, disease, fire, floods or similar events. Catastrophes are modeled by assigning a probability of occurrence and a severity factor ranging from 0.0 (maximum or absolute effect) to 1.0 (no effect). Events with a positive effect (increasing survival or reproduction) also can be modeled by using values greater than 1.0 for the severity effects on reproduction and survival. We used this latter capability to model possible positive effects of a wet phase on the Etosha lion population.

We included four catastrophe events in the simulations (three negative, one positive). The first had a frequency of 3%, a survival severity of 0.93 (a 7% reduction in survival across all age classes), and no effect on reproduction. The second, reflecting a disease epidemic such as rabies, also was estimated at 3% frequency but at a survival severity of 0.66 or 1/3 of the population dying. The positive third event, reflecting the increase in prey availability from an exceptional wet year, was given an estimated frequency of 10% which can be modified if rainfall records are available to estimate an empirical frequency. The severity effect on reproduction was set at 1.5 with no effect on survival. A fourth catastrophe event, based upon projections that CDV reached the Etosha population and became endemic, was modeled separately with a frequency of 10%, survival of 0.66, and no effect on reproduction.

Carrying Capacity (250 and 500, no EV or trend included)

The carrying capacity, 'K' defines an upper limit for the population size, above which additional mortality is imposed across the age classes to return the population to the value set for K. VORTEX uses K to impose density-dependence on survival rates. It also has the capability of imposing density-dependent effects on reproduction that change continuously as the population approaches K. However, since few data are available to evaluate these effects in lion, we elected not to include them in these models.

We used a value of K for Etosha National Park (22,270 km^2) of 250 lion as an estimate of the upper limit of capacity during dry phase years or as a possible management target for population size for Etosha National Park. A value of 500 for K also was used (with other parameter values unchanged) in one set of scenarios to explore the potential an expansion of the population during wet phase years. This change in K will have no effect on the deterministic 'r' but may reduce the probability of extinction and the rate of loss of genetic heterozygosity. We did not include any annual environmental variation (SD) in K or any trend of change in K.

Inbreeding Depression (Not included)

We did not use the option for inbreeding depression included within VORTEX for the lion models. Inclusion of inbreeding depression has minimal effects on the dynamics of populations of 200 or more animals over the time spans of these projections. However, the model does provide information on the rate of loss of heterozygosity and the rate of allelic loss and calculates the rate of inbreeding under different scenarios. This information, combined with generation time estimates provide an estimate of rate of heterozygosity loss per generation.

Starting Age Distribution (stable)

We initialized the model runs with a stable age distribution that distributes the total population among the sex-age classes in accordance with the existing mortality and reproductive schedules using a deterministic Leslie Matrix algorithm. Deterministic values for population growth rate, generation time, adult sex ratio, and age structure are calculated and reported in the output.

Starting Population Size (200)

We used a starting population size of 200 lion representing the present Etosha National Park population in all scenarios.

Iterations and Years of Projection (100 years and 200 repetitions).

Each scenario was repeated 200 times, and projections were made for the next 100 years. Output results were summarized at 5 year intervals as shown in the time series figures. Each scenario tabulated in the tables has a corresponding file number for reference and future retrieval of other results, if necessary. The simulations were run using VORTEX version 7.1 dated January 1996. Comparisons may be made across tables of files with same number (but a different letter prefix) whose parameter values are the same except for the specific parameters being tested in all scenarios in that table.

Sample Input File

A sample input file used to initialize the model for one of the base scenarios for the Etosha lion population is included at the end of this section. The information input for each request and the question are shown in the order in which they appear in the program.

Results

Deterministic Results

We recorded the stochastic 'r' values for each scenario in the tables. These values usually were less than the deterministic values. Deterministic outputs included a value for the growth rate of the population (r, lambda, and Ro), the generation time for males and females, the stable age distribution, and the adult male-to-female sex ratio. Deterministic growth rate was calculated by a Leslie matrix algorithm. Positive values are necessary for a population to survive or grow, and, in principle, a zero value characterizes a stable population. Sustained negative values inevitably lead to extinction. Deterministic growth rate is insensitive to differences in starting population size, K, or environmental variation, but varies with level of mortality, reproductive values, and the additional mortality imposed by catastrophes. The generation times for female lion varied from 8.6 to 8.9 years and from 9.0 to 9.3 years for males. This value is a function of age of first reproduction and maximal breeding age. Thus, there are about 11 to 12 lion generations in 100 years. The male:female sex ratio of adults varied between 0.67 and 0.69.

Stochastic Results

Means (and SD for r and N), calculated over the 200 iterations at 100 years, are given for stochastic population growth rates (r), probabilities of extinction (Pe), final population size (N), retention of genetic heterozygosity (Het), and mean time to extinction (Te) (Tables 1-4). Stochastic population growth rates and the probability of extinction are sensitive to the values and the variances entered for each of the demographic and reproductive parameters. They also are sensitive to population size, inbreeding depression effects, sex ratio, and breeding system.

Stochastic Growth Rate

Population growth rates are sensitive to 'natural' mortality rates in each of the age and sex classes, to the added effects of environmental variation, to human-induced mortality, catastrophe-induced mortality, and to inbreeding depression (if it is a factor). Reproductive rates are sensitive to age of first reproduction, mean litter size, and interbirth interval. Each of these factors may be sensitive to the added effects of environmental variation.

Many scenarios had negative stochastic growth rates (Tables 1-4, Figs. 3 and 9). The scenario based upon the data from the 1980-1986 studies (mean litter size = 2.13, adult female mortality = 7%, and cub mortality of 54%) is #31 in Table 1. This base scenario yielded a negative stochastic 'r' value of -0.033. The family of 'r' values plotted for different levels of adult female mortality and cub mortality (Fig. 3) indicate that the population growth rate will be slightly negative even for a 4% adult mortality under the condition of 54% cub mortality. The population will have a negative growth rate with 10% adult mortality, cub mortalities of 25% or greater, and all values for cub mortality when adult female mortality is 13% (Table 1, Fig. 3).

At a 3.3% rate of decline, the simulated population size decreased about 50% in 20 years. The Etosha population declined about 50% in 4 to 5 years from 1980 to 1985 (Fig. 1) which corresponds to an annual average negative growth rate of about 12 to 14%. This implies an adult female mortality rate of 12 to 15% during this 5 year time period and under the other conditions of the simulations. The recorded excess mortality during this time span ranged from 11 to 23% of the population, nearly sufficient to account for the rapid rate of population decline. An increase in the litter size to 2.7 (Table 2, scenario #L31) increases the growth rate to near zero but the average population size still declines albeit slowly. A decrease in the interbirth interval to 2 years (Table 3, #M31) results in a positive r = 0.043.

Population Size

The average surviving lion population size projected to 100 years, starting from 200 animals, declines for all values of cub mortality at 13% adult female mortality. The size increases at 4% adult female mortality for values of cub mortality up to 54% (Fig. 4, Table 1). Projected changes in average population size, in 5 year steps (Figs. 7 and 8), indicate a gradual increase in population size for cub mortalities of less than 40% at an adult female mortality of 7%. The decline at 54% cub mortality appears to be about 50% in 30 years or 20 to 25% in 10 years. The number of years required to detect this rate of decline by surveys of the population will depend upon the sensitivity and confidence limits of the census methods used. If the average annual adult female mortality is 10%, then the average projected population size will decline for average annual cub mortalities exceeding 30% (Fig. 8).

Increase of the mean litter size to 2.7 with a cub mortality of 54%, interbirth interval of 66%, and adult mortality of 7% still yields a declining population (Fig. 10, Table 2). If the average interbirth interval for all adult females is reduced to 2 years, then the population can increase at a cub mortality rate of 54% (Table 3, Scenario m31).

Probability of Extinction

Projected 100 year population extinctions, with 54% cub mortality, were 36% with 7% average annual adult mortality and 89% with 10% adult mortality (Fig. 5, Table 1). The 100 year extinction rate is 25% at 40% cub mortality and 10% adult mortality. Increasing mean litter size to 2.7 reduces the extinction probability to 1.5% at 40% cub and 10% adult mortality, whereas at

54% cub mortality and 10% adult mortality, the probability of extinction is 42% (Table 2). The Extinction probability is reduced to zero under these conditions when the interbirth interval is 2 years (Table 3).

Loss of Heterozygosity

There was 5% or more loss of heterozygosity in the populations with stochastic growth rates of less than 4%, reflecting that population sizes were fluctuating and growing slowly under these conditions (Figs. 6 and 12). Projected populations that did not grow or that declined in size lost 10% or more of their heterozygosity over 100 years. For long term genetic viability, population conditions should be such that the loss of heterozygosity is less than 0.5% per generation. This would be a loss of 5% or less in 100 years for the lion with 10 to 11 generations in this time span. Values in these scenarios are likely to be underestimates of the rate of loss depending upon the breeding structure of the population and the distribution of life-time reproductive success of males and females.

Disease Catastrophe

The recent CDV epidemic in the Serengeti lion population and the high mortality rates were modeled as a separate catastrophe with a frequency of 10% and a survival severity effect of 0.66 (about 1/3 of the population dying) and no effect on reproduction (Table 4). Addition of this catastrophe event to the scenarios presented in Table 2 (mean litter size of 2.7 and interbirth interval of 3 years) resulted in an average decrease in 'r' of 0.03 to 0.034 across all scenarios (when compared to Table 2 values). An event of this severity and frequency would substantially increase the risk of extinction of the Etosha population, particularly during dry phase years. Mean population size of the surviving populations could decline even if (1) there is no excess mortality of adult females and (2) cub survival improves.

Summary Recommendations

A base scenario for the population, constructed from field data, indicates that (under the conditions and parameter values prevailing during a dry-phase) the lion population has a negative growth rate. Thus long-term survival of the population depends on improved reproduction during the wet-phase years. The demographic impact of the numbers of lion killed during the years 1980 to 1985 is nearly sufficient to account for the observed 50% decline in the total population. If these habitat conditions continue and if adult females continue to be subjected to excess mortality by killing, the population (1) may continue to decline and (2) will be vulnerable to unexpected mortality events such as an epidemic. An increase in mortality caused by the catastrophic introduction of CDV into the population could reduce the mean population growth rate (r) by 0.034, substantially increasing the risk of extinction.

Recommendations

1. Estimate the confidence limits of the census methods as a basis for estimating the number of years required to detect different rates of population change (decline or increase) and as a basis for monitoring the population and adjusting management.

2. Analyse available data on litter size and cub survival on an annual basis to match with rainfall and provide an estimate of environmental variation to use in the models. These measures also may provide an index of changes in prey availability and nutritional status of the population. Consider using these two parameters as a basis for monitoring the status of the population and as useful indices of the effects of management interventions.

3. Evaluate the impact of continued excess loss of adult females during the dry phase years on stability of the population size and on the management target for the population. Develop estimates of the excess losses that can be sustained by the population during the dry-phase years.

4. Evaluate possible inbreeding depression effects and the impact of the excess loss of subadult males and breeding structure on the rate of inbreeding. This can be started by modeling different mortality and breeding scenarios.

Figure Legends:

Figure 1. Estimated and census population size of lion in the Etosha National Park from 1978 to 1994. There was a wet period prior to the study, beginning 1971 and ending in 1979-1980 with higher numbers of prey species and lion.

Figure 2. Recorded numbers (as percentage of the estimated population) of lion killed on private lands neighboring Etosha National Park.

Figure 3. Population stochastic growth rates as a function of interaction of cub and >2 year old mortality rates. The four curves are (from top to bottom) for adult mortality rates of 4%, 7%, 10%, and 13%, respectively. Other parameter values for all scenarios were 2.13 mean litter size, 66% of females with no litter, female age of first reproduction 5 years, initial N = 200, and K = 500.

Figure 4. Projected mean population size at 100 years as a function of juvenile and adult mortality rates. Other parameter values for all scenarios are as in Figure 3.

Figure 5. Projected probability of extinction at 100 years as a function of juvenile and adult mortality rates. Other parameter values for all scenarios are as in Figure 3. The maximum average rate that can be sustained is about 7% under typical arid conditions.

Figure 6. Projected mean per cent heterozygosity remaining at 100 years as a function of juvenile and adult mortality rates. Other parameter values for all scenarios are as in Figure 3. The starting level of heterozygosity is set at 1.00. This measure provides an estimate of the level and rate of inbreeding in the simulated populations. Because the generation time is about 9 years (under the conditions of these simulations) the 100 years represent about 11 generations. Thus, a 100 year mean heterozygosity value of 0.89 represents a loss of 11% or about 1% per generation.

Figure 7. Effects of different cub mortality rates, at an average >2 year old mortality rate of 7% on projected population size over 100 years. Cub mortality rates of 35 to 40% (mean litter size, 2.1) will maintain a near stable population size. These scenarios include increased reproduction for 1 year occurring on average every 10 years.

Figure 8. Effects of different cub mortality rates, at an average >2 year old mortality rate of 10% on projected population size over 100 years. Cub mortality rates of 25 to 30% (mean litter size, 2.1) will maintain a near stable population size. These scenarios include increased reproduction for 1 year occurring on average every 10 years.

Figure 9. Interaction of effects of litter size (2.1 and 2.7 cubs) and interbirth interval (% females with no litter) (66% or 3 years and 50% or 2 years) with different average cub mortality rates on stochastic population growth rate. Adult female mortality was set at 7%. These values encompass the range reported for African lion populations.

Figure 10. Interaction of effects of litter size (2.1 and 2.7 cubs) and interbirth interval (% females with no litter) (66% or 3 years and 50% or 2 years) with different average cub mortality rates on projected mean population size at 100 years. Adult female mortality was set at 7%.

Figure 11. Interaction of effects of litter size (2.1 and 2.7 cubs) and interbirth interval (% females with no litter) (66% or 3 years and 50% or 2 years) with different average cub mortality rates on projected mean probability of extinction at 100 years. Adult female mortality was set at 7%.

Figure 12. Interaction of effects of litter size (2.1 and 2.7 cubs) and interbirth interval (% females with no litter) (66% or 3 years and 50% or 2 years) with different average cub mortality rates on projected mean heterozygosity remaining at 100 years. Adult female mortality was set at 7%.

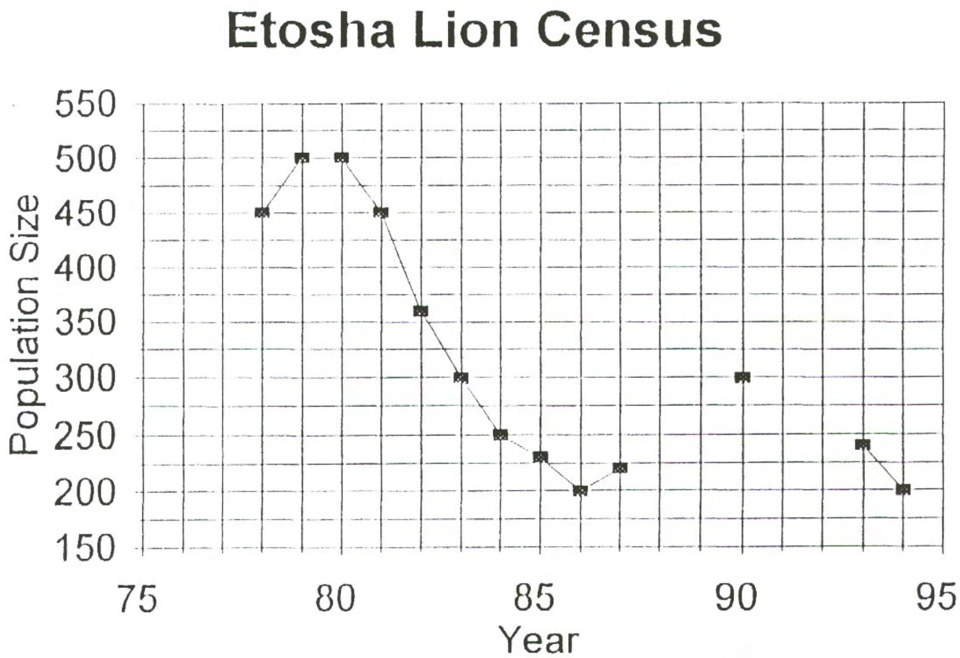

Figure 1. Annual census estimates for lion in Etosha National Park.

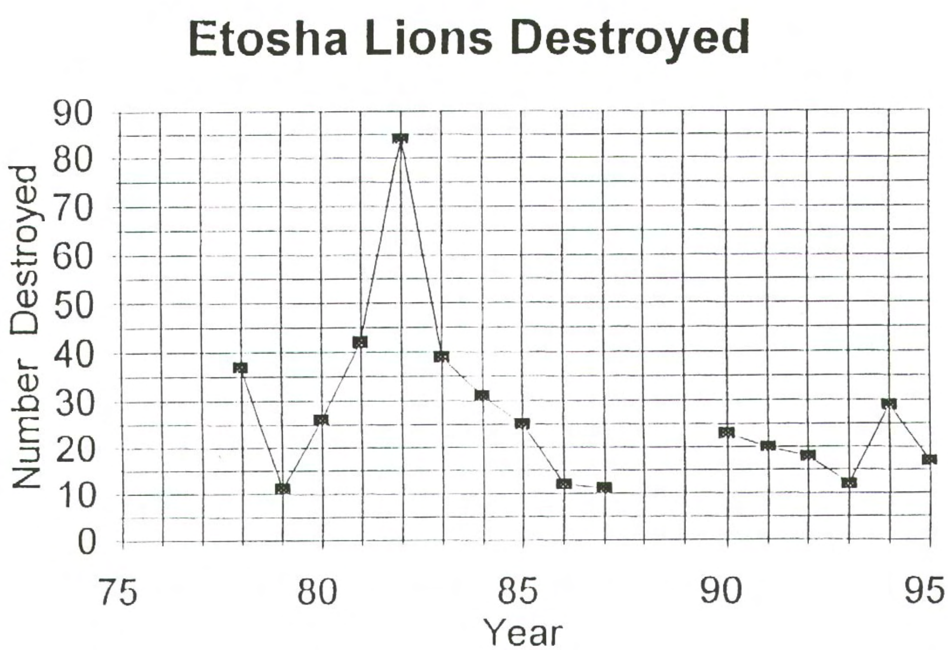

Figure 2. Numbers of Etosha lion known to have been killed on lands around the park. These numbers are considered a minimum estimate.

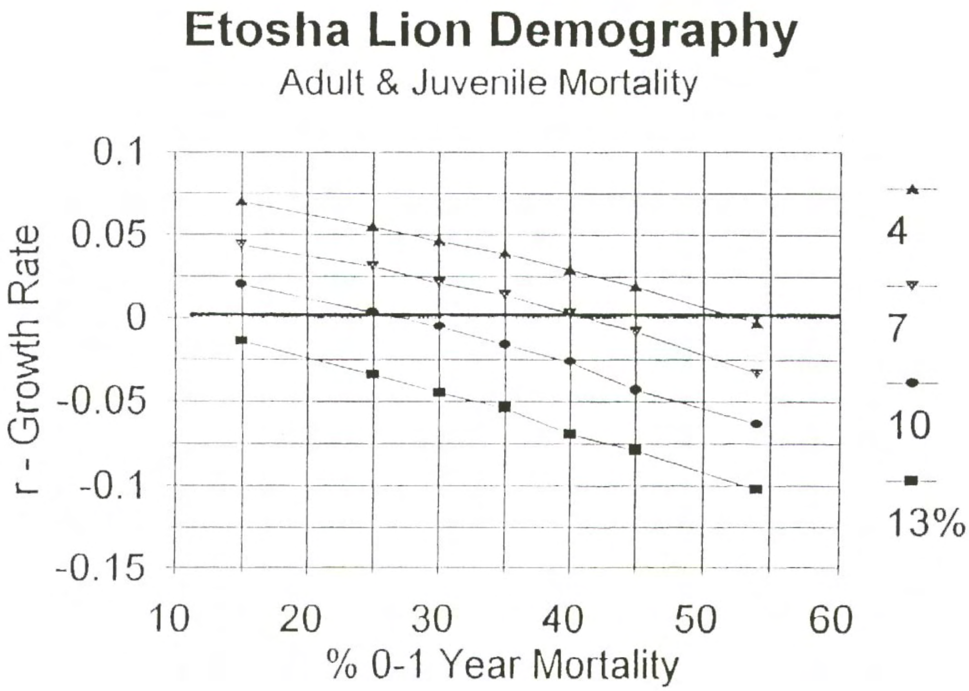

Figure 3. Interaction of adult and cub mortality effects on 'r', population growth rate. Adult female mortality was set at 4, 7, 10, or 13%. Other parameter values as stated in Table 1.

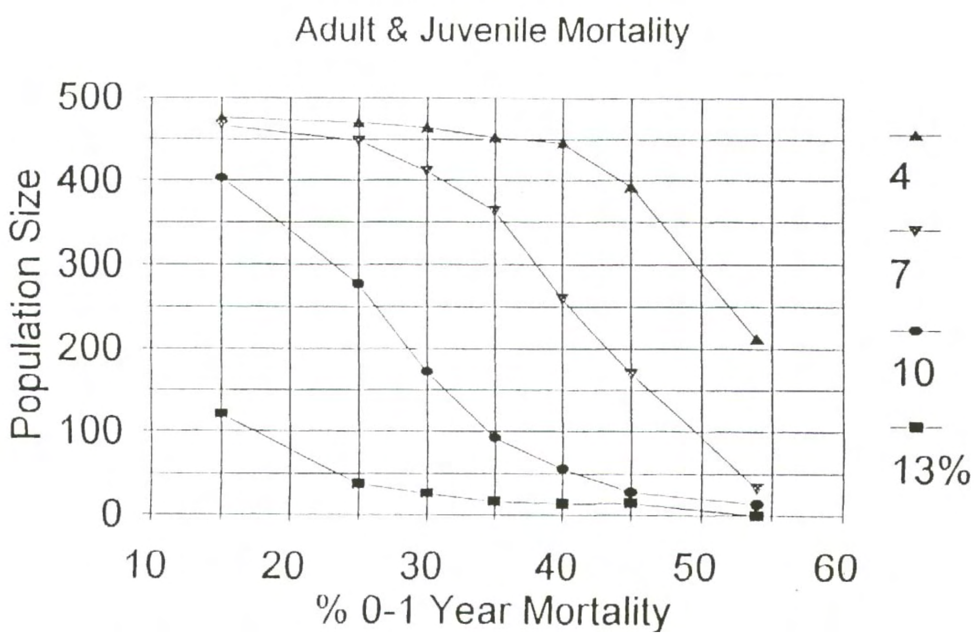

Figure 4. Interaction of adult and cub mortality effects on 'N', projected mean population size at 100 years. Adult female mortality was set at 4, 7, 10, or 13%.

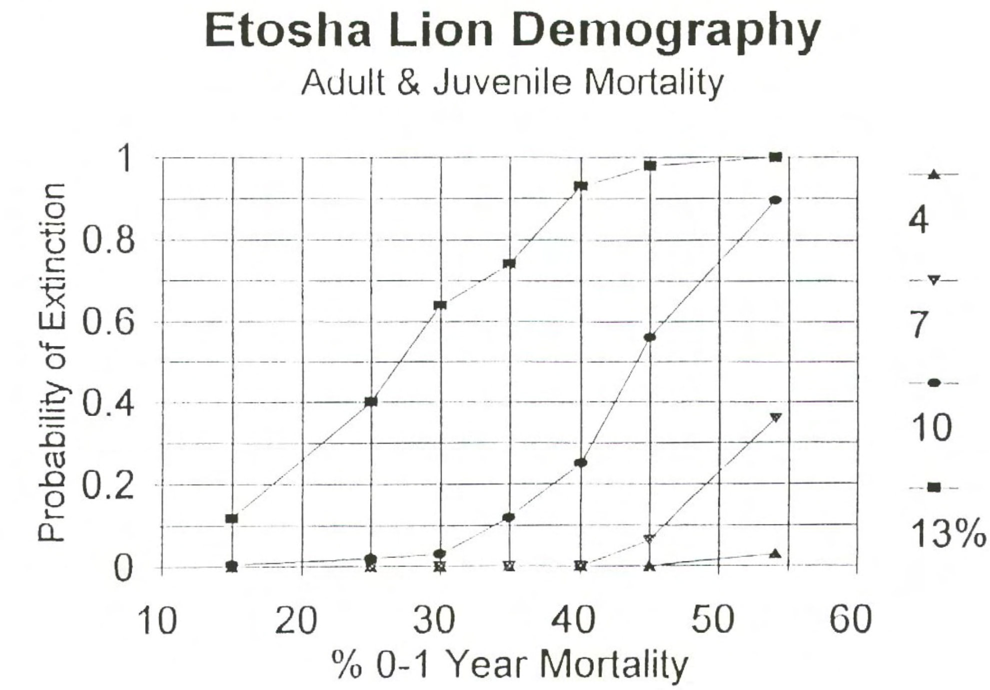

Figure 5. Interaction of adult and cub mortality effects on 'Pe', projected probability of extinction at 100 years. Adult female mortality was set at 4, 7, 10, or 13%.

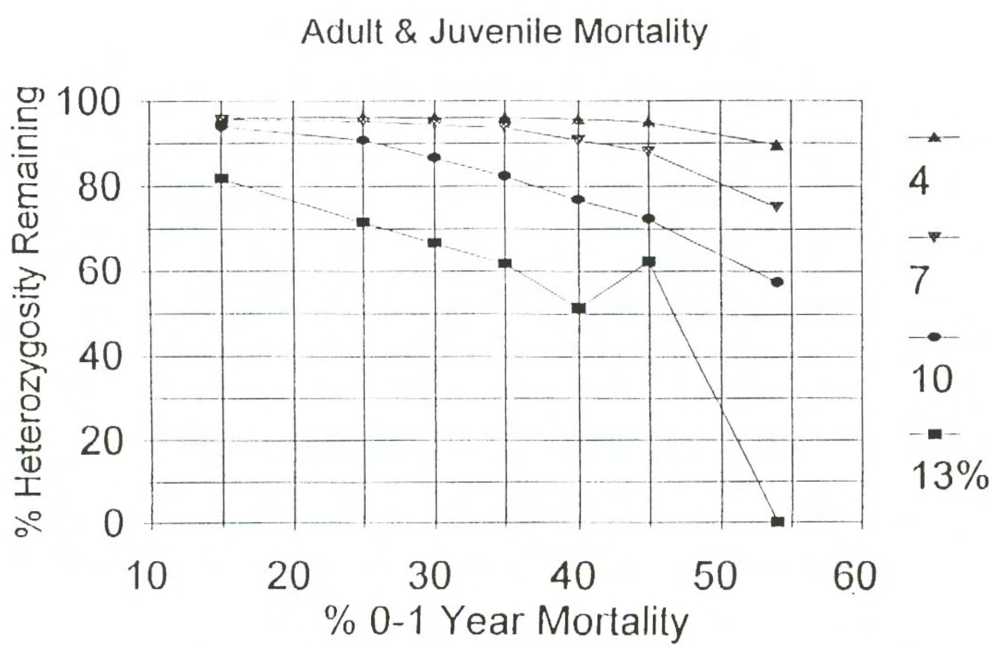

Figure 6. Interaction of adult and cub mortality effects on 'Het', projected mean heterozygosity remaining at 100 years. Adult female mortality was set at 4, 7, 10, or 13%.

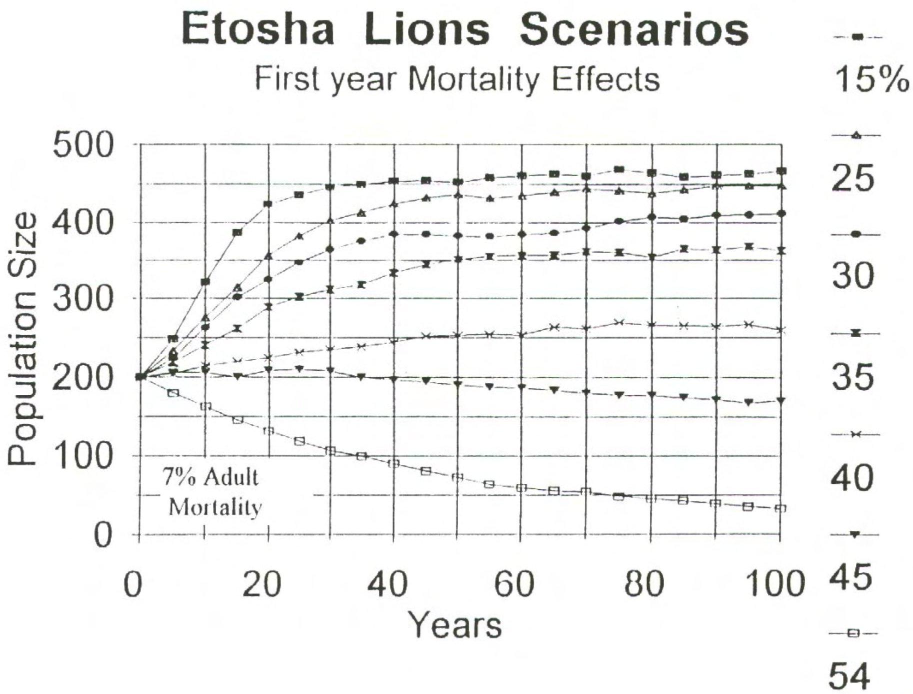

Figure 7. Population size projections, at 5 year intervals for 100 years, for different levels of cub mortality and *7%* adult female mortality.

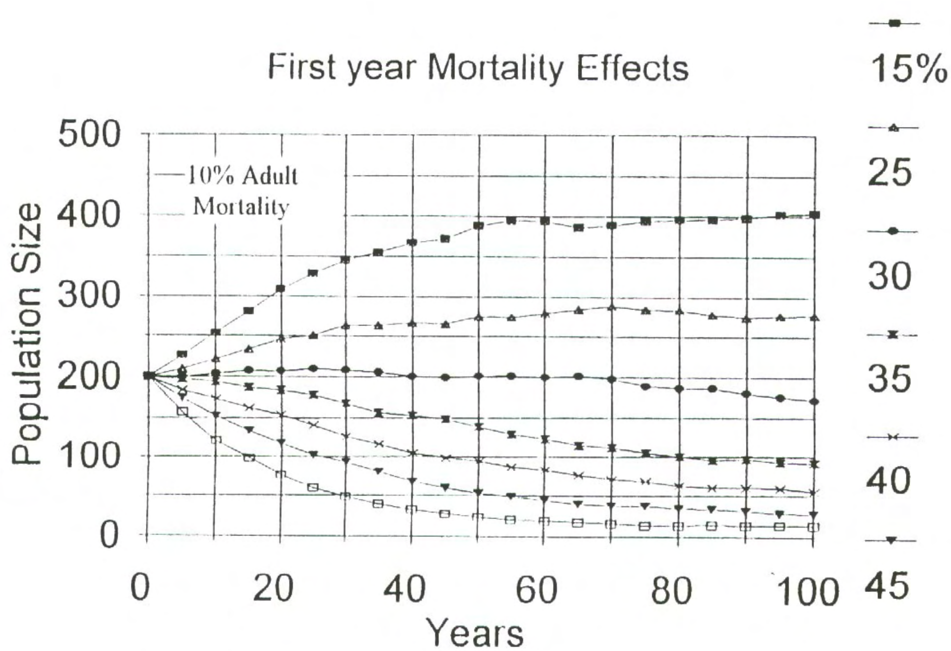

Figure 8. Population size projections, at 5 year intervals for 100 years, for different levels of cub mortality and *10%* adult female mortality.

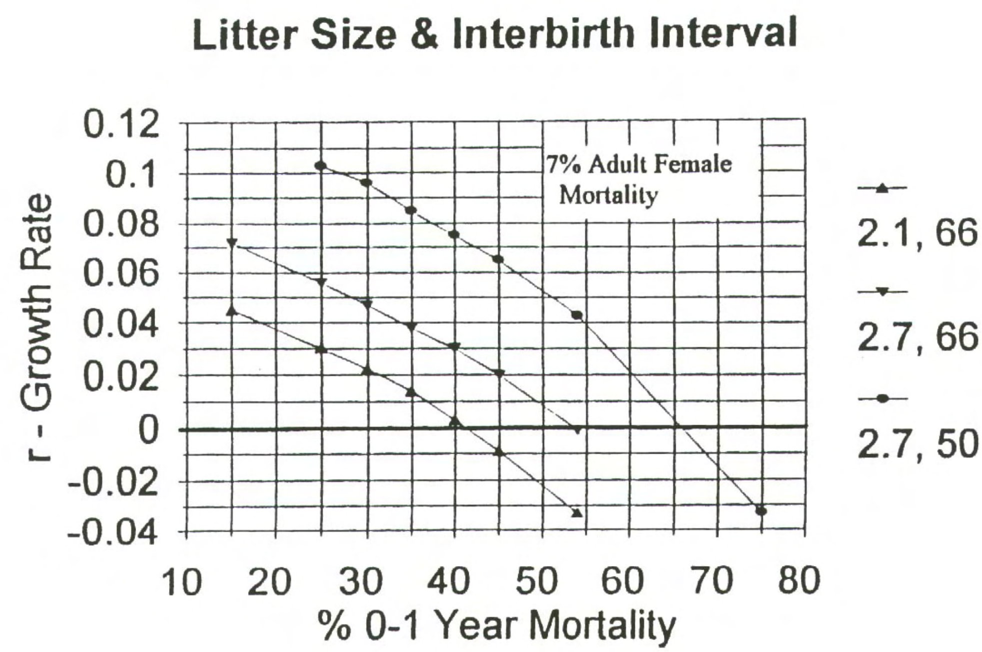

Figure 9. Effects of litter size and interbirth interval (proportion of adult females breeding in a given year) on 'r', population growth rate with adult female mortality = 7% and K=250.

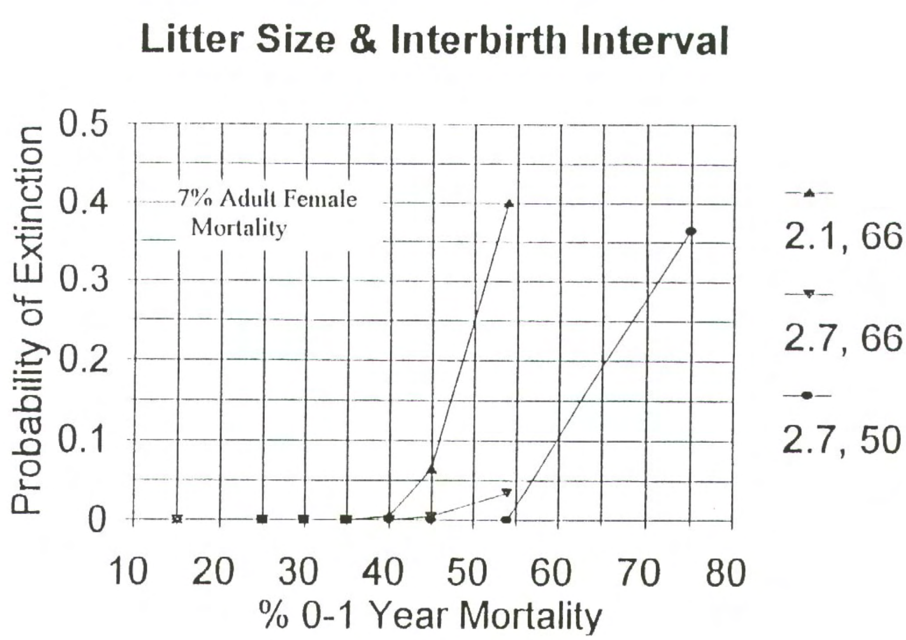

Figure 10. Effects of litter size and interbirth interval (proportion of adult females breeding in a given year) on 'N', mean population size at 100 years with adult female mortality = 7% and K = 250.

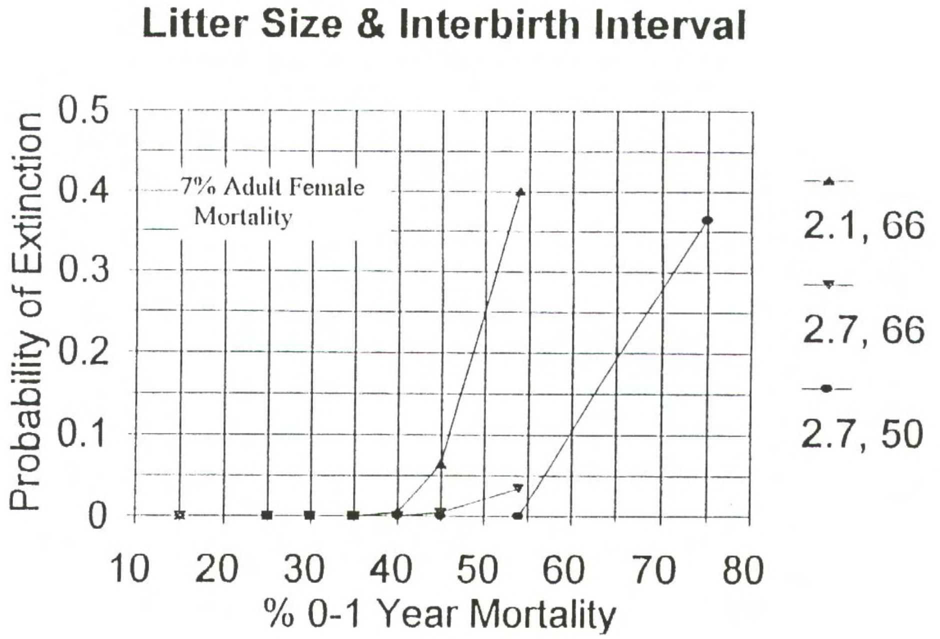

Figure 11. Effects of litter size and interbirth interval (proportion of adult females breeding in a given year) on 'Pe', probability of extinction at 100 years with adult female mortality = 7% and K=250.

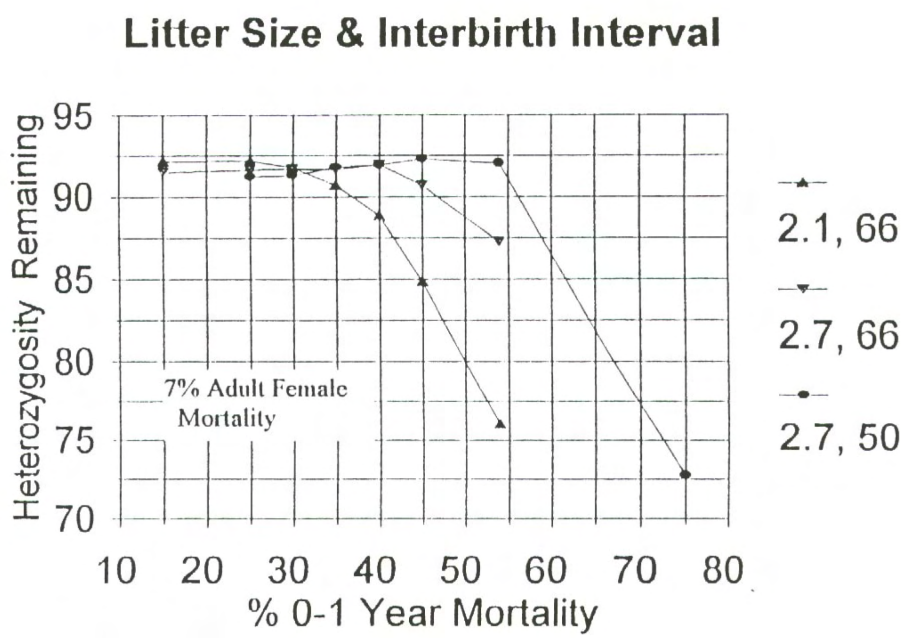

Figure 12. Effects of litter size and interbirth interval (proportion of adult females breeding in a given year) on 'Het', mean heterozygosity remaining at 100 years with adult female mortality = 7% and K=250.

Table 1. Namibian Etosha Lion Population Simulated Demography Scenarios. Interaction of mortality in the 0 to 1 age class with >2 year age classes on population growth rates, probability of extinction, population size, and heterozygosity retained at 100 years. A. simulation of a wet season with increased reproduction and survival occurring at a frequency of 10% (every 10 years on average). Constant conditions were age of first reproduction of female = 5 years and of males = 6 years, maximum age = 14 years, polygynous breeding, 20% of adult males in breeding pool, mean litter size = 2.13 ± 0.68, 66% of all adult females not breeding each year, sex ratio at birth = 0.50. Three catastrophes were included: 1) Freq = 3%, R=1.0, S=0.93, 2) Freq = 3%, R=1.0, S=0.66, and 3) Freq = 10%, R=1.50, and S=1.0. The starting population was set at 200 and K at 500.

File #	0-1 Mort	>2 _ Mort	r stoc	SD	Pe	N	SD	Het	Te
0-1 Mortality = 15%; 'Catastrophe' 3: *S=1.0* (Freq = 10%, R=1.5)									
10	15%	4%	0.070	0.114	0.000	475	50	96.1	0.0
11		7	0.044	0.118	0.000	467	55	95.6	0.0
12		10	0.020	0.123	0.005	403	109	93.9	67.0
13		13	-0.014	0.147	0.120	120	112	81.8	81.5
0-1 Mortality = 25%; 'Catastrophe' 3: *S=1.0* (Freq = 10%, R=1.5)									
14	25	4	0.055	0.112	0.000	470	52	96.1	0.0
15		7	0.031	0.116	0.000	448	74	95.1	0.0
16		10	0.004	0.126	0.020	277	147	90.7	63.0
17		13	-0.034	0.166	0.400	37	37	71.5	74.3
0-1 Mortality = 30%; 'Catastrophe' 3: *S=1.0* (Freq = 10%, R=1.5)									
18	30	4	0.046	0.114	0.000	464	62	96.0	0.0
19		7	0.021	0.116	0.000	411	110	94.4	0.0
20		10	-0.005	0.132	0.030	172	134	86.5	75.0
21		13	-0.045	0.176	0.640	26	23	66.6	76.2
22	35	4	0.039	0.110	0.000	452	69	96.1	0.0
23		7	0.014	0.116	0.000	363	129	93.6	0.0

File #	0-1 Mort	>2 _ Mort	r stoc	SD	Pe	N	SD	Het	Te
24		10	-0.016	0.137	0.120	92	88	82.4	82.2
25		13	-0.054	0.185	0.740	16	13	61.9	68.0
0-1 Mortality = 40%; 'Catastrophe' 3: *S=1.0* (Freq = 10%, R=1.5)									
46	40	4	0.029	0.111	0	446	81	96.0	0
47		***7***	***0.003***	***0.117***	***0***	***260***	***151***	***91.8***	***0***
48		10	-0.026	0.148	0.250	56	53	82.3	79.7
49		13	-0.068	0.191	0.930	14	8	60.4	62.7
0-1 Mortality = 45%; 'Catastrophe' 3: *S=1.0* (Freq = 10%, R=1.5)									
26	45	4	0.019	0.113	0.000	392	120	95.0	0.0
27		7	-0.008	0.129	0.065	170	137	88.0	83.6
28		10	-0.043	0.169	0.560	28	29	72.4	73.2
29		13	-0.079	0.195	0.980	15	16	62.3	57.0
0-1 Mortality = 54%; 'Catastrophe' 3: *S=1.0* (Freq = 10%, R=1.5)									
30	54	4	-0.003	0.116	0.030	213	146	89.6	81.5
31		***7***	***-0.033***	***0.147***	***0.360***	***33***	***37***	***75.1***	***78.8***
32		10	-0.063	0.179	0.895	14	13	57.4	64.3
33		13	-0.102	0.206	1.000	0	0	0.0	45.9
Effects of reproduction and survival enhancements simulating wet season events.									
0-1 Mortality = 30%; 'Catastrophe' 3: *R=1.0, S=1.0* (Freq = 10%)									
42	30	4	0.040	0.112	0	454	69	96.3	0
43		7	0.016	0.112	0	384	121	94.8	0
44		10	-0.010	0.130	0.050	129	113	87.3	80.8
45		13	-0.053	0.183	0.730	17	15	72.6	70.4
0-1 Mortality = 30%; 'Catastrophe' 3: *S=1.1* (Freq = 10%, R=1.5)									
34	30	4	0.051	0.118	0.000	472	54	96.2	0.0
35		7	0.030	0.122	0.000	443	85	95.2	0.0

File #	0-1 Mort	>2 _ Mort	r stoc	SD	Pe	N	SD	Het	Te
36		10	0.005	0.131	0.005	264	139	90.5	96.0
37		13	-0.033	0.169	0.370	37	44	73.6	75.6
0-1 Mortality = 30%; 'Catastrophe' 3: *S=1.2* (Freq = 10%, R=1.5)									
38	30	4	0.054	0.120	0.000	468	59	96.1	0.0
39		7	0.032	0.125	0.000	431	80	95.3	0.0
40		10	0.007	0.137	0.005	293	152	90.9	74.0
41		13	-0.026	0.167	0.275	85	101	77.5	74.8

Table 2. Namibian Etosha Lion Population Simulated Demography Scenarios. Interaction of mortality in the 0 to 1 age class with >2 year age classes on population growth rates, probability of extinction, population size, and heterozygosity retained at 100 years. A. simulation of a wet season with increased reproduction and survival occurring at a frequency of 10% (every 10 years on average). Constant conditions were age of first reproduction of female = 5 years and of males = 6 years, maximum age = 14 years, polygynous breeding, 20% of adult males in breeding pool, mean litter size = 2.7, 66% of all adult females not breeding each year, sex ratio at birth = 0.50. Three catastrophes were included: 1) Freq = 3%, R=1.0, S=0.93, 2) Freq = 3%, R=1.0, S=0.66, and 3) Freq = 10%, R=1.50, and S=1.0. The starting population was set at 200 and K at 250.

File #	0-1 Mort	>2 _ Mort	r stoc	SD	Pe	N	SD	Het	Te
0-1 = 15%. K=250; Litter=2.7. 'Catas.' 3: *S=1.0* (Freq = 10%, R=1.5).									
L10	15%	4%	0.096	0.125	0.000	243	21	91.80	0.0
L11		7	0.072	0.128	0.000	240	24	91.49	0.0
L12		10	0.046	0.133	0.000	229	32	90.41	0.0
L13		13	0.015	0.142	0.015	181	63	87.40	61.7
0-1 = 25%. K=250; Litter=2.7. 'Catas.' 3: *S=1.0* (Freq = 10%, R=1.5).									
L14	25	4%	0.080	0.122	0.000	240	24	92.10	0.0
L15		7	0.056	0.126	0.000	240	22	91.63	0.0
L16		10	0.031	0.131	0.000	223	38	90.65	0.0
L17		13	-0.002	0.145	0.025	123	70	84.16	69.2
0-1 = 30%. K=250; Litter=2.7. 'Catas.' 3: *S=1.0* (Freq = 10%, R=1.5).									
L18	30	4%	0.072	0.121	0.000	240	23	92.57	0.0
L19		7	0.047	0.125	0.000	228	34	91.68	0.0
L20		10	0.023	0.132	0.000	205	49	90.17	0.0
L21		13	-0.010	0.150	0.080	94	68	81.08	77.5
0-1 = 35%. K=250; Litter=2.7. 'Catas.' 3: *S=1.0* (Freq = 10%, R=1.5).									
L22	35	4%	0.063	0.121	0.000	239	23	92.69	0.0
L23		7	0.038	0.125	0.000	224	37	91.61	0.0
L24		10	0.014	0.130	0.000	182	63	88.43	0.0

File #	0-1 Mort	>2 _ Mort	r stoc	SD	Pe	N	SD	Het	Te
L25		13	-0.022	0.159	0.220	64	60	76.28	79.8
0-1 = 40%. K=250; Litter=2.7. 'Catas.' 3: *S=1.0* (Freq = 10%, R=1.5).									
L46	40	4%	0.054	0.119	0.000	230	34	92.82	0.0
L47		7	0.030	0.122	0.000	216	50	91.95	0.0
L48		10	0.005	0.132	0.015	158	72	87.85	89.3
L49		13	-0.036	0.172	0.445	36	38	69.75	72.5
0-1 = 45%. K=250; Litter=2.7. 'Catas.' 3: *S=1.0* (Freq = 10%, R=1.5).									
L26	45	4%	0.043	0.123	0.000	229	35	92.70	0.0
L27		7	0.020	0.129	0.005	198	54	90.69	45.0
L28		10	-0.008	0.145	0.095	109	71	83.70	72.3
L29		13	-0.049	0.190	0.660	19	17	63.99	70.8
0-1 = 54%. K=250; Litter=2.7. 'Catas.' 3: *S=1.0* (Freq = 10%, R=1.5).									
L30	54	4%	0.023	0.123	0.000	204	54	92.14	0.0
L31		***7***	***-0.001***	***0.127***	***0.035***	***135***	***75***	***87.29***	***86.3***
L32		10	-0.034	0.160	0.425	33	32	72.52	75.1
L33		13	-0.073	0.199	0.965	7	4	45.91	61.8
Effects of reproduction and survival enhancements simulating wet season events.									
0-1 = 30%. K=250; Litter=2.7. 'Catas.' 3: *S=1.0* (Freq = 10%, *R=1.0*).									
L42	30	4%	0.067	0.120	0.000	237	27	92.52	0.0
L43		7	0.042	0.122	0.000	230	31	91.98	0.0
L44		10	0.016	0.130	0.010	198	57	89.09	89.0
L45		13	-0.018	0.156	0.195	73	59	79.13	82.2
0-1 = 30%. K=250; Litter=2.7. 'Catas.' 3: *S=1.1* (Freq = 10%, R=1.5).									
L34	30	4%	0.077	0.128	0.000	240	22	92.58	0.0
L35		7	0.056	0.131	0.000	234	28	92.04	0.0
L36		10	0.031	0.138	0.000	208	51	90.51	0.0

File #	0-1 Mort	>2 _ Mort	r stoc	SD	Pe	N	SD	Het	Te
L37		13	-0.001	0.153	0.045	127	74	84.17	76.2
0-1 = 30%. K=250; Litter=2.7. 'Catas.' 3: *S=1.2* (Freq = 10%, R=1.5).									
L38	30	4%	0.079	0.130	0.000	242	22	92.48	0.0
L39		7	0.059	0.134	0.000	232	29	92.00	0.0
L40		10	0.035	0.143	0.000	212	42	90.71	0.0
L41		13	0.006	0.152	0.010	146	73	86.07	85.0

Table 3. Namibian Etosha Lion Population Simulated Demography Scenarios. Interaction of mortality in the 0 to 1 age class with >2 year age classes on population growth rates, probability of extinction, population size, and heterozygosity retained at 100 years. A. simulation of a wet season with increased reproduction and survival occurring at a frequency of 10% (every 10 years on average). Constant conditions were age of first reproduction of female = 5 years and of males = 6 years, maximum age = 14 years, polygynous breeding, 20% of adult males in breeding pool, mean litter size = 2.7, 50% of all adult females not breeding each year, sex ratio at birth = 0.5. Three catastrophes were included: 1) Freq = 3%, R=1.0, S=0.93, 2) Freq = 3%, R=1.0, S=0.66, and 3) Freq = 10%, R=1.50, and S=1.0. The starting population was set at 200 and K at 250.

File #	0-1 Mort	>2 Mort	r stoc	SD	Pe	N	SD	Het	Te
0-1=25%. K=250; Litter=2.7; %F0=50. 'Catas.' 3: *S=1.0,* R=1.5).									
m14	25%	4%	0.128	0.115	0.000	245	19	91.22	0.0
m15		7	0.103	0.118	0.000	245	16	91.20	0.0
m16		10	0.079	0.122	0.000	241	22	90.64	0.0
m17		13	0.049	0.127	0.000	228	35	90.56	0.0
0-1=30%. K=250; Litter=2.7; %F0=50. 'Catas.' 3: *S=1.0,* R=1.5).									
m18	30%	4%	0.118	0.116	0.000	246	16	91.65	0.0
m19		7	0.096	0.116	0.000	244	17	91.31	0.0
m20		10	0.070	0.123	0.000	237	27	90.65	0.0
m21		13	0.039	0.129	0.000	222	40	89.83	0.0
0-1=35%. K=250; Litter=2.7; %F0=50. 'Catas.' 3: *S=1.0,* R=1.5).									
m22	35%	4%	0.110	0.114	0.000	246	15	91.89	0.0
m23		7	0.085	0.117	0.000	244	18	91.78	0.0
m24		10	0.061	0.123	0.000	236	26	90.85	0.0
m25		13	0.030	0.125	0.000	216	46	90.26	0.0
0-1=40%. K=250; Litter=2.7; %F0=50. 'Catas.' 3: *S=1.0,* R=1.5).									
m46	40%	4%	0.100	0.113	0.000	245	18	92.25	0.0
m47		7	0.075	0.115	0.000	239	25	91.92	0.0
m48		10	0.050	0.121	0.000	234	28	91.18	0.0

File #	0-1 Mort	>2 Mort	r stoc	SD	Pe	N	SD	Het	Te
m49		13	0.021	0.127	0.000	207	48	89.52	0.0
0-1=45%. K=250; Litter=2.7; %F0=50. 'Catas.' 3: *S=1.0,* R=1.5).									
m26	45%	4%	0.089	0.120	0.000	244	19	92.47	0.0
m27		7	0.065	0.122	0.000	239	25	92.30	0.0
m28		10	0.038	0.130	0.000	224	37	91.12	0.0
m29		13	0.009	0.138	0.015	161	66	87.39	80.0
0-1=54%. K=250; Litter=2.7; %F0=50. 'Catas.' 3: *S=1.0,* R=1.5).									
m30	54%	4%	0.069	0.120	0.000	237	26	92.86	0.0
m31		7	0.043	0.121	0.000	230	37	92.06	0.0
m32		10	0.017	0.139	0.000	189	59	86.69	0.0
m33		13	-0.016	0.151	0.145	80	64	80.55	81.5
0-1=75%. K=250; Litter=2.7; %F0=50. 'Catas.' 3: *S=1.0,* R=1.5).									
m10	75%	4%	-0.005	0.133	0.055	121	67	87.07	82.5
m11		7	-0.033	0.161	0.365	33	32	72.77	76.8
m12		10	-0.066	0.188	0.905	8	10	58.11	64.7
m13		13	-0.104	0.212	1.000	0	0	0.00	44.8
Effects of reproduction and survival enhancements simulating wet season events.									
0-1=30%. K=250; Litter=2.7; %F0=50. 'Catas.' 3: *S=1.0,* R=1.0).									
m42		4%	0.114	0.111	0.000	244	18	92.12	0.0
m43		7	0.089	0.113	0.000	243	18	91.55	0.0
m44		10	0.065	0.119	0.000	238	23	90.89	0.0
m45		13	0.033	0.125	0.000	222	42	89.95	0.0
0-1=30%. K=250; Litter=2.7; %F0=50. 'Catas.' 3: *S=1.1,* R=1.5).									
m34	30%	4%	0.125	0.120	0.000	245	17	91.65	0.0
m35		7	0.103	0.125	0.000	244	18	91.54	0.0
m36		10	0.078	0.132	0.000	240	21	90.88	0.0

File #	0-1 Mort	>2 Mort	r stoc	SD	Pe	N	SD	Het	Te
m37		13	0.048	0.134	0.000	232	30	90.39	0.0
0-1=30%. K=250; Litter=2.7; %F0=50. 'Catas.' 3: *S=1.2,* R=1.5).									
m38	30%	4%	0.126	0.123	0.000	248	13	91.76	0.0
m39		7	0.105	0.128	0.000	243	22	91.34	0.0
m40		10	0.083	0.136	0.000	237	24	90.70	0.0
m41		13	0.054	0.142	0.000	231	29	90.59	0.0

Table 4. Effect of a disease catastrophe at 10% frequency on the Namibian Etosha Lion Simulated Population Demography Scenarios. Interaction of mortality in the 0 to 1 age class with >2 year age classes on population growth rates, probability of extinction, population size, and heterozygosity retained at 100 years. A. simulation of a wet season with increased reproduction and survival occurring at a frequency of 10% (every 10 years on average). Constant conditions were age of first reproduction of female = 5 years and of males = 6 years, maximum age = 14 years, polygynous breeding, 20% of adult males in breeding pool, mean litter size = 2.7, 66% of *all* adult females not breeding each year, sex ratio at birth = 0.50. Three catastrophes were included: 1) Freq = 3%, R=1.0, S=0.93, 2) Freq = 10%, R=1.0, S=0.66, and 3) Freq = 10%, R=1.50, and S=1.0. The starting population was set at 200 and K at 250.

File #	**0-1 Mort**	**>2 _ Mort**	**r stoc**	**SD**	**Pe**	**N**	**SD**	**Het**	**Te**
0-1 = 15%. K=250; Litter=2.7. 'Catas.' 1: *S=0.66 (Freq = 10%*, R=1.0).									
tL10	15%	4%	0.067	0.164	0.000	225	40	91.02	0.0
tL11		7	0.042	0.167	0.000	202	60	89.58	0.0
tL12		10	0.014	0.177	0.015	152	74	84.26	87.0
tL13		13	-0.020	0.200	0.300	79	68	74.95	71.3
0-1 = 25%. K=250; Litter=2.7. 'Catas.' 1: *S=0.66 (Freq = 10%*, R=1.0).									
tL14	25%	4%	0.052	0.161	0.000	213	50	91.09	0.0
tL15		7	0.027	0.165	0.005	188	63	89.04	95.0
tL16		10	0.000	0.179	0.055	123	78	81.41	64.7
tL17		13	-0.042	0.216	0.600	43	42	70.70	70.0
0-1 = 30%. K=250; Litter=2.7. 'Catas.' 1: *S=0.66 (Freq = 10%*, R=1.0).									
tL18	30%	4%	0.043	0.161	0.000	206	56	90.97	0.0
tL19		7	0.017	0.167	0.015	170	66	87.89	73.3
tL20		10	-0.011	0.184	0.180	96	74	79.69	71.6
tL21		13	-0.051	0.218	0.720	36	44	67.30	66.8
0-1 = 35%. K=250; Litter=2.7. 'Catas.' 1: *S=0.66 (Freq = 10%*, R=1.0).									
tL22	35%	4%	0.034	0.160	0.000	196	59	90.21	0.0
tL23		7	0.009	0.168	0.025	144	76	85.64	84.4

File #	0-1 Mort	>2 _ Mort	r stoc	SD	Pe	N	SD	Het	Te
tL24		10	-0.023	0.195	0.310	74	68	75.63	73.7
tL25		13	-0.061	0.225	0.835	23	30	63.78	64.7
0-1 = 40%. K=250; Litter=2.7. 'Catas.' 1: *S=0.66 (Freq = 10%*, R=1.0).									
tL46	40%	4%	0.025	0.159	0.005	196	59	89.82	55.0
tL47		7	-0.002	0.172	0.080	117	77	83.45	69.3
tL48		10	-0.033	0.194	0.425	48	48	75.38	71.1
tL49		13	-0.069	0.226	0.895	18	21	60.03	60.1
0-1 = 45%. K=250; Litter=2.7. 'Catas.' 1: *S=0.66 (Freq = 10%*, R=1.0).									
tL26	45%	4%	0.015	0.164	0.020	167	71	89.06	84.5
tL27		7	-0.014	0.180	0.170	82	69	80.31	73.6
tL28		10	-0.046	0.207	0.635	29	32	66.26	70.0
tL29		13	-0.084	0.235	0.965	10	7	50.99	52.2
0-1 = 54%. K=250; Litter=2.7. 'Catas.' 1: *S=0.66 (Freq = 10%*, R=1.0).									
tL30	54%	4%	-0.008	0.168	0.085	93	72	83.03	71.1
tL31		7	-0.042	0.199	0.550	29	31	71.62	69.8
tL32		10	-0.068	0.217	0.905	12	9	58.78	60.4
tL33		13	-0.106	0.238	0.995	14	0	67.86	43.4
Effects of reproduction and survival enhancements of wet season events.									
0-1 = 30%. K=250; Litter=2.7. Catastrophe 3: *S=1.0* (Freq = 10%, *R=1.0*); & Catastrophe 1: *S=0.66 (Freq = 10%*, R=1.0).									
tL42	30%	4%	0.038	0.159	0.005	208	53	90.66	72.0
tL43		7	0.012	0.165	0.010	158	73	85.86	77.0
tL44		10	-0.016	0.186	0.245	89	67	79.16	75.8
tL45		13	-0.058	0.220	0.810	19	16	65.93	65.5
0-1 = 30%. K=250; Litter=2.7. Catastrophe 3: *S=1.1* (Freq = 10%, *R=1.5*); & Catastrophe 1: *S=0.66 (Freq = 10%*, R=1.0).									

File #	0-1 Mort	>2 _ Mort	r stoc	SD	Pe	N	SD	Het	Te
tL34	30%	4%	0.050	0.164	0.000	217	46	91.32	0.0
tL35		7	0.027	0.167	0.000	188	64	89.05	0.0
tL36		10	0.002	0.180	0.040	125	77	83.00	74.2
tL37		13	-0.036	0.208	0.505	48	47	73.81	68.7
0-1 = 30%. K=250; Litter=2.7. Catastrophe 3: *S=1.2* (Freq = 10%, *R=1.5*); & Catastrophe 1: *S=0.66 (Freq = 10%*, R=1.0).									
tL38	30%	4%	0.051	0.167	0.000	216	50	91.06	0.0
tL39		7	0.028	0.172	0.020	191	62	88.44	73.8
tL40		10	0.004	0.183	0.050	131	78	82.52	75.0
tL41		13	-0.032	0.211	0.445	52	47	72.18	70.2

Nlionk47 ***Output Filename***
Y ***Graphing Files?***
N ***Each Iteration?***
Y ***Screen display of graphs?***
200 ***Simulations***
100 ***Years***
5 ***Reporting Interval***
1 ***Populations***
N ***Inbreeding Depression?***
N ***EV correlation?***
3 ***Types Of Catastrophes***
P ***Monogamous, Polygynous, or Hermaphroditic***
5 ***Female Breeding Age***
6 ***Male Breeding Age***
14 ***Maximum Age***
0.500000 ***Sex Ratio***
4 ***Maximum Litter Size***
N ***Density Dependent Breeding?***
66.000000 ***Population 1: Percent Litter Size 0***
3.000000 ***Population 1: Percent Litter Size 1***
25.000000 ***Population 1: Percent Litter Size 2***
5.000000 ***Population 1: Percent Litter Size 3***
1.000000 ***Population 1: Percent Litter Size 4***
15.790292 ***EV--Reproduction***
40.000000 ***Female Mortality At Age 0***
10.000000 ***EV--FemaleMortality***
10.000000 ***Female Mortality At Age 1***
3.000000 ***EV--FemaleMortality***
7.000000 ***Female Mortality At Age 2***
2.000000 ***EV--FemaleMortality***
7.000000 ***Female Mortality At Age 3***
2.000000 ***EV--FemaleMortality***
7.000000 ***Female Mortality At Age 4***
2.000000 ***EV--FemaleMortality***
7.000000 ***Adult Female Mortality***
2.000000 ***EV--AdultFemaleMortality***
40.000000 ***Male Mortality At Age 0***
10.0000000 ***EV--MaleMortality***
10.000000 ***Male Mortality At Age 1***
3.000000 ***EV--MaleMortality***
9.800000 ***Male Mortality At Age 2***
3.000000 ***EV--MaleMortality***
9.800000 ***Male Mortality At Age 3***
3.000000 ***EV--MaleMortality***
9.800000 ***Male Mortality At Age 4***

3.000000 ***EV--MaleMortality***
9.800000 ***Male Mortality At Age 5***
3.000000 ***EV--MaleMortality***
9.800000 ***Adult Male Mortality***
3.000000 ***EV--AdultMaleMortality***
3.000000 ***Probability Of Catastrophe 1***
1.000000 ***Severity--Reproduction***
0.930000 ***Severity--Survival***
3.000000 ***Probability Of Catastrophe 2***
1.000000 ***Severity--Reproduction***
0.660000 ***Severity--Survival***
10.000000 ***Probability Of Catastrophe 3***
1.500000 ***Severity--Reproduction***
1.000000 ***Severity--Survival***
N ***All Males Breeders?***
Y ***Answer--A--Known?***
20.000000 ***Percent Males In Breeding Pool***
Y ***Start At Stable Age Distribution?***
200 ***Initial Population Size***
250 ***K***
0.000000 ***EV--K***
N ***Trend In K?***
N ***Harvest?***
N ***Supplement?***
n ***AnotherSimulation?***

Disease Working Group Report - Lion

Betsy Fox, Linda Munson (facilitators), David Balfour, Mitch Bush, Mark Jago, Lynn Kramer, Jock Orford, Rosemary Orford, Melody Roelke-Parker, Hermann Scherer, Byron Stein, Christian Walzer, Kumiko Yoneda

Problems:

1. There was consensus that disease is a potential threat to Namibian lion population viability.

2. There was consensus that we lack sufficient information on disease prevalences in Namibian lion to develop long-term management recommendations to minimize disease threats.

3. There was consensus that the biomedical laboratories in Namibia need additional training, equipment, and supplies to conduct priority disease surveillance for lion.

Defining the Diseases that are a Threat to the Population:

1. Infectious Diseases in Wild Lion

Feline Immunodeficiency Virus (FIV):

The current Etosha population is assumed to be FIV negative. Forty-four lion from Etosha, tested by Western blot procedures, revealed no antibodies to FIV. Other Etosha lion and lion from other Namibian populations need to be tested by this procedure to determine the true FIV status in this regional population. The potential disease threat in populations that are seronegative is presumed greater than in populations that have high seroprevalence, because the latter likely have successfully evolved with the virus. The economic value of Namibian lion is greater than if the population became infected.

Canine Distemper Virus (CDV):

The Serengeti lion CDV epidemic demonstrates that the new CDV biotype in East Africa is highly lethal to lion. Because CDV is highly contagious and because there are many species throughout Africa that can facilitate spread, the potential for a catastrophic epidemic in Namibian lion is substantial.

Rabies:

Because rabies has been documented in Etosha lion and persists in the ecosystem, lion mortalities from rabies are expected intermittently.

Feline coronavirus, feline panleukopenia virus (parvovirus), feline herpesvirus 1, anthrax, tuberculosis, feline leukemiavirus, feline calicivirus, hemoparasites, ectoparasites, endoparasites, and toxoplasmosis:

All of these pathogens could cause lion morbidity and mortality. The degree of threat is unknown.

2. *Impact of Translocation and Animal Transfers on Diseases*

Transfer of animals between sites could increase pathogen transmission between captive facilities and between ecosystems. Also, common holding sites for translocating wild lion will concentrate pathogens, exposing these lion to unnaturally high doses which may overwhelm natural resistance. Therefore, unregulated animal movements may increase the prevalence of infectious diseases in captive and wild populations. (See Appendix VII)

What is Needed to Address the Problems:

1. Know the prevalence of infectious disease in Namibia.

2. Know the pathogenicity of strains of infectious diseases in Namibia (e.g., FIV and CDV).

3. Train Namibian veterinarians and laboratory personnel in procedures to diagnose lion diseases.

4. Train farmers and field personnel to collect the biomaterials needed for disease monitoring.

5. Define the applied research projects to identify effective preventative measures.

6. Create a captive management plan to minimize disease (See Appendices VI and VII).

7. Identify funding to meet the needs for surveillance, *in situ* training, and applied research.

Immediate Action Plan Recommendations

1. Actions to Define Disease Threats

a. Inform Namibian veterinarians during the Namibian Veterinary Congress (17-18 February 1996) of the proposed disease monitoring program for Namibian lion.

b. Determine the current exposure to FIV and anthrax in Namibian lion by conducting appropriate testing on previously archived frozen serum samples.

i. FIV antibodies should be assessed in all available Namibian lion sera by Western blot analysis, currently the most reliable method available. The Western blot test is more sensitive and specific than the IDEXX CITE-Combo^{R} test which results in false negative and positive results. Western blot tests for FIV are performed by Dr. Stephen O'Brien (U.S.A.) and Dr. Margaret Barr (U.S.A.)

c. Determine historic patterns of infectious diseases in predators and their prey in Namibia and of infectious diseases in domestic pets which are transmissible to lion.

i. All unpublished data from Etosha, the Central Veterinary Laboratory, and agricultural records should be combined with all available published reports to define the history of infectious diseases of lion in Namibia. This summary will provide the basis for immediate disease control strategies.

ii. We propose completing this task during 1996 with student volunteers supervised by Namibian veterinarians.

d. Initiate prospective disease monitoring programs for Namibian lion.

i. Begin collecting, banking, and evaluating biomaterials from all lion that are handled or that die. Due to limited funding, the first year will focus on forming an effective network throughout Namibia to collect and store biomaterials. All available fixed tissues should be evaluated by histopathology without delay, and selected serology (e.g., for FIV, CDV, and anthrax) should be conducted. Costs for diagnostic procedures hopefully will be waived during the first year while funding sources are identified.

ii. The proposed network for biomaterials collection and storage will include veterinarians in private practice, Ministry of Environment and

Tourism personnel, NGOs, and possibly field researchers.

iii. Biomaterials recommended for collection and storage include fixed and frozen tissues, hair, whole blood, serum, plasma, blood smears, and semen.

e. Evaluate habitat and environmental factors that concentrate pathogens.

i. Determine the effect of dry/wet cycles and seasons on pathogen concentrations in the ecosystem.

ii. Determine the effects of wildlife and livestock management practices, such as the construction of artificial water-holes, on the concentration of pathogenic agents.

f. After 3 years, collate all prospective and retrospective data to redefine disease threats to Namibian lion.

i. Utilize these results to reassess disease threats to Namibian lion populations and define new priorities for surveillance and research.

ii. Communicate results to all concerned parties. Ongoing communications should occur at meetings and through the publications of regional farmer, hunter, and veterinary associations, and the scientific literature.

2. Actions to Identify Funding for Disease Monitoring and Applied Research

a. Submit a grant proposal to NGOs and other private funding sources within 1 year for a comprehensive, long-term disease monitoring project for Namibian lion. Initial costs of this program will be high due to the need for equipment (estimated at N$25,000 to 40,000) to collect, store, and evaluate biomaterials and to enhance regional laboratory capabilities through training (N$150,000). Subsequently, funding will be required for supplies (N$5000/year) and costs for diagnostic tests (N$155,000/year). Funds also will be needed for a Curator of Biomaterials (N$36,000) and for regional travel N($100,000). Funds will be managed locally through the Veterinary Clinicians Forum.

b. Once disease monitoring programs are established, then seek funding for applied research projects, such as a CDV vaccine trial on lion.

3. Actions to Standardize Disease Surveillance Programs and Preventative Measures

a. Design protocols for consistent collection and storage of biomaterials. Protocols will be reviewed for feasibility within Namibia by regional veterinarians. Protocols to be used by non-veterinary personnel will include illustrations of tissues and collecting procedures. Non-veterinarians will receive instruction from veterinarians on methods of biomaterial collection. A curator of biomaterials will be designated to maintain inventories and monitor access to the biomaterial banks. The protocols for processing, labeling, and storing samples will be consistent with CBSG Genome Resource Bank recommendations.

b. Designate sites and techniques for evaluating lion biomaterials in Namibia. Sites will be chosen based on the abilities of existing personnel to perform the optimal tests and quality assurance from the laboratories. Considerable concern was expressed about the ability of existing laboratories in Namibia to perform these tests.

c. Create a communication network on lion diseases involving all concerned parties. It was recognized that the veterinary community has a strong, pre-existing communication network for domestic animal diseases that involves veterinarians, farmers, and the Ministry. This network should assist in communicating about wildlife disease threats.

d. Design protocols for translocations. The feasibility of these protocols should consider the constraints of:

i. Need to immediately move animals from traps to a holding site.

ii. Delay inherent in comprehensive infectious disease screening. Translocation protocols will include shipping and quarantine standards, required tests for infectious diseases and the acceptable results, vaccination and anti-parasiticide recommendations, housing standards, and minimum standards for physical examinations and medical records.

e. Design protocols for captive management. The Medical Procedures section of the Lion Species Survival Plan Husbandry Manual of the American Zoo and Aquariums Association should be adapted to meet specific needs of Namibian lion.

f. Enhance existing vaccination programs for domestic cats and dogs in regions with lion populations. Supplement current rabies vaccination programs with vaccination against CDV in dogs and parvovirus, herpesvirus, and calicivirus in cats. The program should include education concerning the benefits of vaccinating pets. This should be an ongoing program that is initiated within 2 years.

g. Design an epidemic response plan for lion that includes veterinarians, Ministry officials, and other concerned parties. Recommendations for the response plan include designing strategies for defining the extent of a given epidemic and containing the epidemic, designating routes of communication, devising strategies for vaccination of endangered wildlife, isolating threatened populations, and collecting/banking gametes to assist in 'insuring' populations.

h. Initiate collection and banking of infectious disease-free semen to assure against catastrophic loss of the population from disease. Semen can be managed through a regional Genome Resource Bank.

4. Immediate Actions to Conserve the Current Health Status of the Namibian Lion

a. Test all lion that are to be moved (within or out of the country) for FIV antibodies by Western Blot. Any FIV-positive animal should not be translocated, and strict quarantine standards should be imposed.

b. Strict quarantine standards should be observed during translocations.

Models of Disease Threats to Namibian Lion Populations for the PHVA VORTEX Model

1. CDV: Based on the Serengeti CDV epidemic in lion, assuming that the Serengeti CDV biotype was the infectious agent, and that all lion in the population lacked neutralizing antibodies to this biotype, then a 50% mortality can be predicted in areas were pride territories overlap.

2. Rabies: Based on historical data from Etosha, a model would predict a 5 to 7% mortality every 15 to 20 years in lion.

Genetics Working Group Report - Lion

Stephen O'Brien, Jan Martenson (facilitators), Tom Priesser, Joelle Wentzel

Problems:

1. There is a question as to the genetic and demographic prognosis for the small, isolated free-ranging lion populations in Namibia.

Solution/strategy:

a. Assess the extent of genetic diversity in the Etosha and Kaudom populations using molecular genetic indices (these being the only viable populations).

b. If this analysis reveals that the lion in these two populations are outbred and stable, they may not be as susceptible to genetic threats as other lion populations (e.g., in the Ngorongoro Crater). At the same time, the potential for future demographic reduction (which has occurred in similar small lion populations in the Gir Forest in India and the Ngorongoro Crater in Tanzania) should be considered, especially in Etosha because of its isolation. (There exists the possibility that the Kaudom population may be contiguous with the Botswana population, although no documented interactive access exists to date.) The future possibility of facilitated introduction to reverse a demographic or genetic loss should not be excluded.

c. If the molecular analysis indicates that the lion do not represent outbred populations, the option of facilitated genetic exchange (e.g., translocations) among free-ranging Namibian lion populations should be considered.

Adequate and informative genetic analysis depends on evaluating the many samples already collected from Etosha and Kaudom lion. However, more samples may be needed. Genetic analysis should be performed in laboratories which already have extensive experience with lion. Collection and analysis can be linked with Solution/Strategy below.

2. Unusual behavior and pride structure have been observed among Etosha lion. additionally, there is an imbalance in age/sex ratio in the lion killed on farms bordering Etosha National Park (50% are subadult males). A lack of parentage and kinship data makes it difficult to interpret these observations and to assess the impact of losing large numbers of subadult males or overall population stability.

Solution/strategy:

a. DNA analysis (with mini- and micro-satellite probes) would provide useful parentage and kinship information. From this information, pride structure and reproductive success could be determined. Radio-collaring and more frequent observation of prides would supplement the molecular genetic study. Answers to the above should be forthcoming as field research is on-going, and collaborations for kinship analysis are underway and can be linked with Solution/Strategy 1. Radio-collaring will proceed as funds are secured.

3. There is a perception among wildlife managers that the Etosha lion are a recognizable subspecies that would be unsuitable as a source of genetic material for supplementing depleted South African populations. The animals are unique in their FIV-free status and would be an invaluable resource for infusing new genetic material into compromised lion populations outside Namibia.

Solution/strategy:

a. Screen the South African populations for presence/absence of traits that may confirm or refute Etosha subspecies status.

b. Examine the status/success of previous introductions of Namibian lion into South African populations.

Data collected from Solution/Strategy 1 would contribute to part (a). South African field biologists could provide information on (b).

Should the importance of Etosha lion be realized more fully as a result of this action, it is hoped that their perceived value in Namibia would be increased, thus providing a further incentive to conserve them. Exportation of lion also may provide another solution for dealing with problem animals.

4. There is a lack of understanding of the management consequences of having small founder populations of lion on game farms/reserves.

Solution/strategy:

Develop practical guidelines for selecting founders of known origin and for managing small populations based on demographic simulation models. Guidelines should be developed by interested game farm managers and farmers aided by information obtained from the lion source.

Captive Populations Working Group Report - Lion

Jack Grisham (facilitator), Karl Ammann, Bruce Davidson, Claudia Feiss, Mike Fouraker, Cheryl Green, JoGayle Howard, Mandy Schumann, Tarren Wagener

Goal: The development of a management plan for captive populations that will include all animals held in captivity. This plan should interface with the international community (i.e., countries with free-ranging populations as well as those with captive populations) in the long-term management of the species.

Defining the Namibian captive population: For the purposes of this document, a captive population is comprised of non-free-ranging animals that are managed on an individual basis and are not self-sufficient. There are two types of captive-held animals: (1) permanently held in captivity (i.e., pets, tourism) or (2) held temporarily before translocation. There are approximately six facilities permanently holding lion in captivity in Namibia (totaling 20 to 30 individuals), primarily for tourism uses. Namibia currently has minimal legislation regulating facilities that hold lion.

Action Steps:

1. Current legislation and policy should be reviewed in the light of the recommendations contained within the final PHVA document. A coordinating body should be established to control the fate of animals moving into and within captivity. This body should be responsible for the administration and approval of all permits for the capture and/or transportation of lion. A basic principle should be minimal movement of animals from point of origin. All protocols should be developed and reviewed by the central representative coordinating body. It is recommended that a Namibian Studbook for African lion be developed, which ideally should interface with an International Studbook. This preferably should be via the Internet.

a. Standards need to be established to control the handling and housing of animals moving into and within captivity, taking special cognizance of (among others) the following factors (see Appendix VI for more details):

> Husbandry standards including (but not limited to) enclosure size, water source, shade, enrichment (rocks, platforms, etc.), fencing type, enclosure location (close to other animals or visitors), and hygiene.

Nutrition, including quantity, variety and type of feed, supplementation, and feeding schedules.

Health, including infectious disease status, and vaccination protocols.
Breeding guidelines, including gestation, litter size, special care, housing (maternity den), hand-raising guidelines, and birth control.

b. Controlling movement and of captive animals (especially those temporarily held in captivity) through a coordinating body (commission) will require:

A central organization for assimilating and coordinating supply and demand and discouraging random advertisements by international zoos and hunters.

Cooperation of international zoos and hunters (i.e., suppliers and demanders) by having fair representation on the commission.

Regional “rapid response teams” consisting of volunteers or persons who willingly will quickly locate and collect problem animals (especially lion that are most difficult to retrieve alive).

Central or regional holding points for screening, quarantine, housing, and permanently identifying animals while awaiting decisions on fate.

Legislation to support the powers of the central controlling body (commission) that ultimately should approve all applications for permits to capture and export lion.

2. Management goals for the captive Namibian lion populations are:

Developing a genome resource bank (GRB) (see Appendix V for more details).

Providing a source of animals for reintroduction/relocation, tourism, education, research, export, and other highly worthwhile enterprises.

3. A captive population of FIV-free lion derived from Namibia as an insurance policy against the possible extinction of this unique population should be established. These animals would be available for breeding, relocation, tourism, education, and export. It is suggested that fifteen breeding pairs (25 to 30 animals) would be needed to maintain this population, with an infusion of new genes from a few additional individuals periodically in the future. These also would be used for genome resource banking (developing a GRB).

Recommendations Summary:

1. The Namibian Government should appoint a commission in the next 6 months to examine existing regulations and then advise about promulgating new legislation deciding the appropriate handling and dispensation of lion brought into captivity.

2. The Namibian government should consider implementing a revised lion policy using the information generated from this PHVA process for the ultimate purpose of creating a national lion management plan.

3. The Namibian government should consider establishing a central representative coordinating body within the next 12 months, whose function will be to set standards for captive lion management. In the interim, the government should consider establishing a program to assess the general health and disease status of the existing captive lion population.

4. Captive Namibian lion may serve as a valuable resource of genetic material for long-term conservation purposes and as a hedge against catastrophe. Therefore, a genome resource banking action plan (GRB) is recommended. Such a plan should be developed and implemented within the next 12 months.

POPULATION AND HABITAT VIABILITY ASSESSMENT FOR THE NAMIBIAN CHEETAH (*Acinonyx jubatus*) AND LION *(Panthera leo)*

11-16 February 1996
Otjiwarongo, Namibia

Workshop Report
February 1997

SECTION 4

APPENDICES

Appendix I

STATEMENT BY HIS EXCELLENCY PRESIDENT SAM NUJOMA

ON THE OCCASION OF THE POPULATION AND HABITAT VIABILITY ANALYSIS WORKSHOP

12 FEBRUARY 1996
OTJIWARONGO

Mr. Chairman
Honourable Minister of Environment and Tourism
Your Excellency, Ambassador Marshall McCallie
Dear Participants
Ladies and Gentlemen,

It is a great pleasure for me to have been invited to officially open this important workshop. I am filled with pride that Namibia is given the honour and responsibility to host an international workshop on the cheetah, which is Africa's most endangered large cat, and the lion -- that majestic symbol of the continent.

At the outset, I would like to welcome all participants to the workshop. A special word of welcome goes to those participants who come from outside our borders. In addition to local and regional delegates, I am informed that we have amongst us delegates from other parts of Africa and others from as far afield as the United States of America and Europe. You are all welcome indeed.

As Patron of the Cheetah Conservation Fund, I would also like to congratulate the organisers of the workshop for doing their best to give this workshop an international flavour. It is also commendable that the organisers saw it fit to involve local farmers, ranchers, and veterinarians in this effort.

Namibia is today home to the last large population of cheetah in the world. It, therefore, goes without saying that with such an asset, a great deal of responsibility has been placed on our shoulders. It is a responsibility that the Government, nongovernmental organisations, farmers, and private individuals must address collectively. In our efforts to fulfill this duty, we must avoid the temptation of neglecting or passing our duties to others. When it comes to environmental conservation, be it our flora or fauna, we all have something to contribute towards the effort.

Ladies and Gentlemen, I would not be over-emphasizing when I repeat again and again that the only effective way to protect the environment is for the Government, the scientific community, the private sector, and the local people to collaborate in their efforts.

We in Namibia have introduced a Lion Policy which aims at protecting that species which is also endangered in the wild. It is my hope that this workshop will set in motion preparations, not only of Namibia's National Cheetah Plan, but also the preparation for an international cheetah plan covering all countries and territories wherever cheetah populations can be found. Just as the international community of nations has adopted protocols and conventions to protect several other endangered species, I do not see any reason why it cannot be done for the cheetah.

Ladies and Gentlemen, I mentioned earlier that collaboration between Governments and other social entities provides a winning strategy in conservation. I would like to mention here that such conservation efforts should not be impeded by national borders. Just as our wildlife does not recognize such borders, our efforts to protect them and conserve them must be uniform and not border-bound. In other words, we must find ways whereby conservation strategies can be harmonized to allow for effective conservation on a global scale.

As it has been said, the global village is becoming increasingly smaller, which makes co-operation and coordination inevitable and necessary.

As citizens of the world we must recognize the importance of teaching our children the values and the importance of environmental conservation and protection. We are living in times that are rapidly changing. As such, we must all adapt our lifestyles to these changing circumstances.

It has now become a necessity that environmental education should be part of each and every child's school curriculum. In that manner, they will grow up with the appreciation for protecting the natural environment and its wildlife. That in turn enables them to protect and conserve the environment and its sub-systems for their children and generations to come.

Ladies and Gentlemen, in developing countries such as Namibia, conservation of the environment presents many positive spin-offs. While protecting the lives of endangered animals, our efforts will and can promote the tourist trade. There is widespread consensus that tourism is set to grow and become an important economic sector, especially in the economies of Southern African States. I, therefore, believe the resources that we invest in environmental conservation today will eventually pay off.

It is my sincere hope that all participants present here today will learn a great deal from each other. Since delegates come from such diverse backgrounds, there is no doubt that the exchange of ideas and experiences will be most enriching. The presence of many experts in the field of conservation as well as farmers and community members who are in continual contact with the animals concerned will contribute greatly to the deliberations and dialogue that will get underway during the course of the workshop.

Ladies and Gentlemen, it is a sad truth, however, that in some instances nature conservation has been pursued at the expense of, and at times to the detriment of, human populations sharing the same habitats as the animals or plants targeted for conservation. It is my wish that this workshop looks critically at the dilemma of nature conservation on the one hand, and the preservation of humans and their livelihoods, on the other.

I would like to emphasize that our responsibility lies with both environmental conservation and safeguarding the interests of human beings and their livelihoods. It is my belief that this can be done. All we have to do to achieve it, is to find sustainable ways in which nature and human beings can co-exist peacefully. In fact, many Namibian farmers already serve as models of good wildlife and habitat management for other countries where lion and cheetah can be found.

A workshop of this nature provides a forum where conservationists from around the world can come together to devise new strategies, improve upon existing ones, and compare notes. It is my call to you that we must all do our best to protect our earth and preserve it for the coming generations. Our efforts must be coordinated regardless of what part of the globe we may come from. If we do not, posterity will judge us for having neglected a sacred duty.

Finally, I would like to wish all the participants fruitful and productive deliberations during the workshop.

With these words, I now declare this workshop officially open.

I thank you.

Appendix II

SPEECH OF MINISTER OF ENVIRONMENT & TOURISM

CHEETAH AND LION PHVA WORKSHOP
12-17 FEBRUARY 1996

Mr. Chairman, visitors to Namibia, workshop participants,

It is my honour today to make some introductory remarks before the start of this serious and important workshop.

It is common knowledge that we take our wildlife conservation matters very seriously in Namibia and Southern Africa as a whole, and we like to think that we have made significant advances in this field.

In Namibia, we believe strongly that the only viable conservation policy is one that is based on the sustainable use of our natural resources. This principle is even spelled out in our Constitution, and I would like to refer to Article 95 of our Constitution which reads as follows:

Article 95: Promotion of the Welfare of the People

> The State shall actively promote and maintain the welfare of the people by adopting, inter alia, policies aimed at the following:

(I) maintenance of ecosystems, essential ecological processes and biological diversity of Namibia and utilisation of living natural resources on a sustainable basis for the benefit of all Namibians, both present and future;

Mapping out a future is more problematic for some species than for others, and these include specifically the large carnivores. These species are not easily confined to protected areas, and are responsible for major damage and irritation in farming areas. Protected areas are seldom large enough to contain viable populations of large predators such as lion and cheetah, and it appears inevitable that some new management options will have to be developed in order to maintain such species through the next century.

At first glance, the odds that any wild cheetah and lion will be left on the farming areas of Southern Africa in the next century are very small indeed. Everywhere people are encroaching on wildlife habitat in a way that leads to the exclusion of wildlife - with the dangerous large cats amongst the first to disappear. Everywhere, that is, except where a new set of rules are followed. I refer here to a knowledge of simple economics, a basic understanding of costs and benefits and what motivates people. Many of us today believe that conservation is not exempt from human nature or economics and indeed is just one more alternative form of land management! This sounds cruel and cold, but in Southern Africa we have seen a form of land management develop where the value of wildlife, including the large carnivores, has been found to exceed the damage that they cause. The growth in eco-tourism and sport hunting as well as the commercial demand for live specimens have made it possible for us to become somewhat more optimistic over the future of cheetah in particular.

Few people can afford to conserve animals such as lion and cheetah purely for the sake of conservation or some deep ethical or moral imperative. Most of the citizens of our region have to make do with the resources available to them - and these are often not in great abundance. As a consequence, people cannot easily absorb the damage done by the large predators as well as other depredations on their livelihoods caused by drought, disease, market fluctuations, stock theft, and all the other imbalances. I was shocked to learn that cheetah are not even welcome or tolerated on most of the game ranches in Namibia, as they prey on expensive re-introduced rare antelopes, etc. In the large parks, they are apparently suppressed by lion and hyenas.

Where will they then survive? On the cattle ranches? We have a great deal of problems ahead, which will require our best efforts, or else lion and cheetah might only survive as semi-tame tourist habituated relics in a few game reserves.

This workshop has therefore come at an opportune moment for three reasons:

First: Namibia is a co-proponent of a down-listing petition for cheetah in the U.S. Endangered Species Act. Both the petition and the Act are currently under review and are controversial. I feel that the commitments made by our landowners and hunting community towards cheetah conservation deserves recognition, including the opening of the U.S. market for sport-hunting. We already have an export quota from CITES, and there is no reason why any market should remain closed arbitrarily. We also believe that we as Namibians are in the best position to evaluate conservation options for our species.

Second: I have just recently obtained Cabinet approval to increase the status of lion (and wild dogs) in Namibia to protected species - meaning that landholders may only legally destroy these species where there is a real and immediate threat against the lives of people and livestock, and must then report such a killing within a set period of time. We know that it is difficult to prove whether or not lives were actually threatened by wild animals, and if the killing of lion on a farm was justified. But we hope that the legal requirement to report such incidents will at least give us new insight into the scale of the problem. This is not all that we need to do to secure the future of lion in Namibia. More needs to be done, and I hope that you will come up with new ideas.

Third: My Ministry has launched an initiative to draft a national cheetah conservation plan, hopefully something that all the various organisations involved with cheetah issues in Namibia can subscribe to, and we will make use of all the information and ideas generated at this workshop. We are happy that so many people and organisations are involved, as Government alone cannot deal with the complex problems at hand. However, we need to work together rather than against each other, and each party needs to know what everybody else is planning to do. I hope this initiative will be supported by all the organisations present here.

Although a major focus this week will be the Namibian populations of lion and cheetah, we are not alone, and our populations are not isolated. In the past year, we have had incursions of lion from South Africa, Angola, and Botswana, and who knows where our lion and cheetah have been. We need to expand the excellent level of co-operation that we have achieved within the region on rhino and elephant management to include other species, such as the large carnivores.

I trust that with these few introductory remarks, I have started the ball rolling. I hope that you will have fruitful discussions of this very interesting and very important programme and I hope that all visitors to Namibia will enjoy their stay and that they will come again. You are most welcome.

I thank you.

The Honourable Gert Hanekom

Appendix III

Population and Habitat Viability Assessment Workshop
11-16 February 1996, Otjiwarongo, Namibia
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Appendix IV

Ode to the Otjiwarongo Cheetah and Lion PHVA Workshop
by Frans Ferrera

For me the week's conversations have come to an end.
I want to conclude with a few words, my friend.

The farmers say "Please kill them - keep the numbers down"
My spouse and her daughter want a new dressing gown.
My bank manager says "Please stop my friend,
there is no money for a new holiday tent."

The conservationists say "We want more land!!"
In that way the numbers will expand.

The scientists say "We will take the semen,
and x-ray it with lots of venom
to make them vigorous and highly fertile,
let them grow and catch the eye
of people who love them and don't want them to die!!"

The government says "What is the matter?
We will keep going on with lots of chatter.
Money is the big problem today;
what can we do anyway?
We must keep the people happy
and distribute the lot.
For so many spoons, we need a bigger money pot."

The cause of the problem is visible and clear.
There are too many people on earth, my dear.
The solution is, I would say, intervene in mans' reproductive way.
Sterilize the women
Castrate the men
Then we can try for a better balance again.

Development of a Genome Resource Bank for Cheetah and Lion in Namibia

The cheetah and lion stand as symbols for the importance of African wildlife conservation. These felids have extraordinary charisma and, as a result, serve as models for why humans should care about and conserve nature. Almost all school-age children can imitate the lion's roar and tell you that the cheetah is the speediest creature on earth. But more importantly, these species are large carnivores at the top of nature's food chain. Their survival is vital to the entire ecosystem; their extinction would most likely create a catastrophic "domino" effect on other species, ultimately decreasing biodiversity.

Of all African countries, Namibia has a unique challenge to conserving wildlife, largely because most wild animals live on farmlands. The cheetah and lion are no exception, and therein lies the problem because these species can prey on livestock. Ways to circumvent this human-animal conflict are discussed in other parts of this document. Nonetheless, it is a general conclusion of this workshop that productive farming can be sustained in conjunction with an integrated and intensive management plan for wild felids. For the cheetah, solutions will involve the frequent capture of cheetah on farmlands for translocation and re-release. Because these animals represent an extraordinarily valuable resource of genes and Namibian heritage, it is recommended that a National Genome Resource Bank be established for the cheetah and lion.

Justification for Genome Resource Banks

A Genome Resource Bank, or GRB, is the organized collection, storage and use of biomaterials, especially sperm, embryos, tissues, blood products, and DNA. The cryopreservation of such materials is an emerging "tool" that has enormous implications for the assessment, conservation, and sustainable use of natural resources. A GRB is not established for the purpose of replacing living animals in nature or in zoos. The mission of a GRB is to support existing efforts to preserve species and all currently available genetic diversity within those species.

There are many practical advantages of a GRB for facilitating cheetah and lion conservation. For example,1. An organized GRB could provide a repository of frozen gametes, embryos, tissues, blood products, and DNA. The value of a GRB for a wild population could be enormous by helping to provide 'insurance' against catastrophes, especially emerging diseases, natural disasters, and social/political upheaval. The cheetah and lion populations may suddenly become infected with sinister viruses, similar to the recent canine distemper epidemic that decimated the East African lion population. Availability of frozen serum and tissue that have been collected over time could be used to retrospectively identify the onset and cause of diseases. Pathogen-free gametes and even embryos could be made available to re-derive disease-free populations.

2. A GRB would not be merely a static warehouse of biological materials, but would serve a vital, interactive role between free-living populations and captive populations. Germ plasm from wild stocks could be incorporated into captive breeding programs without removing animals from the wild. Breeding programs in captivity are especially important as a (a)reservoir of genetic diversity, (b) source for studying cheetah and lion biology, and (c) tool to educate the public about the need for wild cheetah and lion to co-exist with humans. There also is the potential of augmenting genetic diversity in free-living (fragmented) populations through the periodic capture and artificial insemination of wild females that are captured briefly and then returned pregnant to the native habitat.

3. The combination of frozen gametes and embryos and reproductive techniques such as artificial insemination, *in vitro* fertilization, and embryo transfer offers unique opportunities for improving breeding efficiency. Cryopreservation of germ plasm extends the generation interval of founder animals indefinitely by allowing cross-generational propagation. The genetic diversity of the founder animals does not die with the animal, but remains viable and available for future generations.

4. Germ plasm banking has the effect of reducing the number of animals needed to ensure that high levels of genetic diversity are retained within a population. This reduces capital and operating costs of captive breeding programs and provides space for other species at extinction risk.

5. Transporting frozen sperm or embryos eliminates the considerable risks associated with the transport or exchange of live animals.

6. A GRB would not be limited to animal germ plasm (i.e., sperm) but would include other biomaterials like serum, plasma, white blood cells, red blood cells, tissues, and DNA useful for addressing subspecies, hybridization, and parentage questions. These biomaterials also would be useful for molecular and systematic forensics and disease surveillance.

7. The systematic use of germ plasm for intercrossing subspecies (such as South African and East African cheetah) may provide avenues for assessing the impact of intercrossing on genetic diversity and population viability.

Cheetah GRB

Almost 20 years of research have resulted in a huge biological database for the cheetah. This massive amount of information is available not simply on the ecology of the species, but also on its unique genetics and fascinating reproductive characteristics. All of this information has been integrated to allow successful artificial insemination to become fairly predictable in the cheetah. This is especially important in captive breeding programs because it eliminates the need to move animals from one location to another. More importantly, the ability to use cryopreserved sperm from Namibian cheetah precludes the need to remove more cheetah from the wild for zoos. Cheetah can remain in the wild where their presence helps maintain habitat for other species and the ecosystem.

The value of artificial insemination already has been demonstrated by a collaborative relationship among the Namibian Ministry of the Environment and Tourism, the Cheetah Conservation Fund, and a group of North American zoos. In 1994, these organizations assessed the feasibility of using cryopreserved sperm transported internationally to produce cheetah by artificial insemination. Sperm samples were collected from captive-held or recently-caught wild cheetah in Namibia. These samples were cryopreserved, imported into the U.S., and used on a selective basis to artificially inseminate known genetically-valuable females that had never reproduced. To date, two litters and four cheetah cubs have been produced. One cub, a female, survives and is healthy. She represents a milestone - the first demonstration of the use of cryopreserved sperm shipped transcontinentally to produce an endangered species.

Lion GRB

The lion also has been the focus of intensive research on genetic analysis, reproductive/endocrine studies, and health assessments of both African and Asian lion. An extensive world-wide survey on the incidence of feline immunodeficiency virus (FIV) in lion has demonstrated that the lion population in Namibia is FIV negative. Because the prevalence of FIV in lion is extremely high in surrounding countries (>90% in South African lion), Namibian lion are unique and represent one of the few remaining FIV-free populations in Africa. Techniques for cryopreserving lion sperm have been established. Therefore, the initiation of a GRB for lion would allow the immediate capture of a valuable, disease-free resource. Also, the Namibian lion population (~300 individuals) is becoming increasingly fragmented. Since the largest population consists of only ~200 lion in Etosha National Park, a GRB could preserve existing genetic diversity.

A foundation of basic knowledge on assisted reproduction techniques, including *in vitro* fertilization and artificial insemination, exists for lion. Hormonal induction of estrus and ovulation has been attempted in lion; however, further study is needed on ovulation induction protocols. To date, no offspring have been produced in lion using assisted reproduction. Because it has been demonstrated that frozen cheetah sperm can be used to produce offspring, it is anticipated that cryopreserved lion sperm (using the same cryopreservation technique as in cheetah) will be viable for producing *in vitro* and/or *in vivo* embryos once hormone protocols are further refined.

Recommendations for Establishing Genome Resource Banks

It is recommended that:

1. A Genome Resource Banking Action Plan should be developed in accordance with guidelines established by the IUCN-World Conservation Union's Conservation Breeding Specialist Group. An action plan is a highly detailed document that deals with the need for establishing a GRB and the important issues related to collection, storage, ownership, accessibility, and use of biomaterials. Because a GRB Action Plan is being developed in North America under the umbrella of the Cheetah Species Survival Plan (SSP), it is recommended that the Action Plan incorporate both regions. This formal cooperative plan will be established within 1 year with the initial primary partners being the Namibian Ministry of Environment and Tourism, the Cheetah Conservation Fund, the North American Cheetah SSP and Lion SSP, and other relevant conservation organizations.

2. The biomaterials collected from cheetah and lion living on private or public lands should be the property of the government (country) of Namibia. The Ministry of Environment and Tourism-Directorate of Resource Management shall make the final decision about the disposition of biomaterials. This will be controlled, in part, through the export permit process. Details will be set forth in the action planning document to be developed.

3. The scientific collection and storage of all biomaterials for cheetah should be coordinated by the Cheetah Conservation Fund in collaboration with Namibian State Veterinarians of the Ministry of Agriculture. Biomaterials from lion will be coordinated by the Namibian Ministry of Environment and Tourism and the Namibian State Veterinarians of the Ministry of Agriculture. This will be accomplished by establishing and securing a Cheetah GRB and Lion GRB, including a site for secondary storage (as a second insurance site). The coordinators will distribute the material by acting as a liaison between the Ministry of Environment and Tourism, local veterinarians, interested scientists, zoos, and other relevant organizations world-wide.

4. No monetary value should be placed on any biomaterials to discourage the commercialization, or worse, the capture and exploitation of cheetah and lion. The cost of establishing and operating the GRB should be supported by institutions throughout the world interested in conserving cheetah and lion. One example is that workshop participants from North American zoos are confident in their ability to secure some funding to support the GRB program. Additionally, it is recommended that the Ministry of Environment and Tourism consider accepting 'in-kind' support for such a program in the form of donated equipment.

5. Further research is needed to enhance the efficiency of assisted reproduction in lion using cryopreserved sperm. Studies should be conducted on hormonal stimulation of estrus and ovulation, time of ovulation, and optimal time of insemination using frozen-thawed spermatozoa.

6. As the GRB Action Plan is prepared, the distribution of and accessibility to biomaterials in the GRB will be more readily available to organizations that are contributing to conservation

programs in Namibia, either through direct monetary support of the Cheetah Conservation Fund (or other high priority programs) or through providing in-kind support and training.

7. The Ministry of Environment and Tourism-Directorate of Resource Management, the Cheetah Conservation Fund and other relevant national organizations will receive full acknowledgment by any individual or organization that uses biomaterials from the GRB. Furthermore, any offspring produced from the use of cryopreserved gametes or embryos would remain the sole property of Namibia, largely for the purpose of documenting and advertising the contributions of Namibia to conserving one of its most precious natural resources.

Appendix VI

Development of a Management Plan for Captive Cheetah and Lion in Namibia: preliminary discussions *

For the holistic conservation of cheetah and lion within Namibia, the development of a coordinated adaptive management plan for all animals in captivity should be considered. Captive programs for these species may be integrated into the global zoo network, thus, work to contributing to the worldwide conservation of these species.

Suggested Minimum Captive Management Guidelines

The following are husbandry guidelines for consideration. A major component for the care and management of the captive lion and cheetah is the design of the area in which the animal is housed. When designing enclosures, husbandry needs, veterinary concerns, and the biological requirements of the species should be considered. Important factors include dimensions, substrate, shelter, transfer areas, and climate, all of which can influence both animal health and reproduction.

Enclosure Design: Basic enclosure design is of the utmost importance. Size must be adequate for movement and exercise to decrease boredom, stimulate activity, and give a feeling of security and comfort. Naturalistic areas may be created by using areas of varied topography such as a combination of elevated areas, dead-fall trees, rocks, and mounds. Logs or timbers allow the natural behavior of scratching for claw wear and maintenance.

The enclosure area should be subdivided into a main and holding area for animals temporarily isolated/separated from the main enclosure. Holding areas in an enclosure are essential to proper management and health care and include additional working, maternity, holding, and quarantine areas. Holding areas provide treatment areas out of view and seclusion for a stressed or ill animal. Within this area, squeeze or restraint cages permit an alternative method of handling for procedures normally requiring anesthesia.

A minimum enclosure area for a single lion or cheetah should measure at least 10 m x 6 m deep (60 sq. m); areas should be 50% larger per additional animal. Although adults do not climb well, their leaping ability should not be underestimated. Holding areas should measure at least 2.4 m x 2.4 m per animal. Owners not wanting young or who are unable to use birth control implants or neutering, should build separate cages to separate adults.

Introduction and Breeding: Flexibility is the key to successful introductions of individuals unknown to each other. Individual personalities and animal characteristics must be considered. For any introduction, adequate personnel should be available to intervene, keeping in mind that severe aggression may occur. Methods for intervention and separation include transferring one or more of the animals to another area, or using of a jet of water from a hose.

If breeding is a consideration, mate selection is an important factor. Consideration should be given to broaden genetic representation of the individuals. It is important to have a separate maternity area to isolate a female before impending birth. This area can be adjacent to the main holding area, but should have a small gauge fence near the bottom to prevent any injuries to cubs. The area should be sufficiently large enough so that the female can move her cubs away from the main holding area if needed.

General Husbandry: Although cheetah and lion normally live in a warm climate year round, most are tolerant of wide temperature extremes. Animals always should have access to shade and, if housed indoors even temporarily, should be protected from extreme temperatures. If held indoors, animals should have adequate light. Fresh clean water for drinking should be available at all times. Watering sources either should be built into the enclosure area or be sturdy containers fastened to prevent over-turning. Water containers should be cleaned and disinfected daily. Some lion enjoy bathing or swimming, and pools may be incorporated.

Enclosure size usually will dictate cleaning frequency. Smaller enclosures will become soiled more often and, thus, require regular cleaning. Concrete areas and the areas where animals are fed should be cleaned daily. Dirt substrates should be raked and spot-cleaned daily.

Nutrition: Whole animal carcasses (ungulate, rabbits, fowl) may be alternated to vary the diet. Healthy cheetah or lion of optimum weight may be fasted one to two times per week.
It is important to feed the carcass intact because skin, bone, and organ meat are important components of overall health and oral hygiene.

Caution must be taken if feeding only muscle meat from freshly butchered livestock because vitamin/mineral needs may not be met (calcium is the most critical). The supplement Calsup should be used in these cases. Owners should be wary of carcasses obtained from road kills or donations because of contamination potential. Living animals selected as food sources for cheetah and lion should be inspected to ensure they are disease-free. Diets containing high percentages of fowl must be supplemented with calcium.

Health: Services of a veterinarian should be available. Specific guidelines for health monitoring of captive cheetah in Namibia are being developed by the Namibian Veterinary Association.

All animals in captivity should be identified by one or more permanent methods at the first opportunity. It is recommended that each animal be tattooed (inner aspect of the thigh) and/or receive a subdermal, electronic transponder (base of tail). Transponders have a 5% failure rate. If resources allow, a second transponder should be placed at the dorsal base of the ear. It is customary to tattoo or ear-implant females left, males right. When available, studbook numbers should be used to identify each specimen.

Special Requirements: Lion

Lion are the largest predator in Africa, and males achieve weights of 150 to 250 kg. Females are somewhat smaller at 120 to 160 kg.. The lion has a gestation of approximately 105 days, and produces a litter of 2 to 5 cubs.

Lion are the most social cat species. Lion may be kept singly, although it is recommended they be maintained in pairs or prides. Only one adult male should be mixed with a female, or group of females, at any one time to ensure accurate recording of parentage. It may be possible for a number of single sex groups to be established, particularly in game parks. These groups can act as a reservoir that can be utilized should a particular individual be needed.

Special Requirements: Cheetah

The cheetah is morphologically and behaviorally unlike the lion. A diurnal species, the cheetah is physically adapted for running at high speeds over short distances. Although approximately the same length as most large felids, cheetah are much lighter in build and weigh only 35 to 57 kg. Like other large felids, males are larger. Gestation is 90-95 days and litter sizes are 3-5.

In the wild, cheetah tend to be solitary or live in coalitions. Adults may be maintained as pairs or in large groups with little difficulty.

* see also *Cheetah Husbandry Manual,* American Zoo & Aquarium Association, Bethesda, MD.

Appendix VII.
Quarantine and Translocation Guidelines

At the PHVA workshop and subsequent Veterinary committee meetings, veterinarians most involved with cheetah/leopard capture and translocations, plus Cheetah Conservation Fund (CCF) representatives, discussed standards and recommendations for quarantine and translocations for cheetah and lion. The following protocols are based on these discussions and existing protocols from the American Association of Zoo Veterinarians (AAZV) Universal Veterinary Procedures Manual and CCF protocols. The recommendations are subject to modification. Protocols for Genome Resource Banking/Sample Handling and Captive Management still need to be finalized, as they require more extensive work and review. Furthermore, Namibian veterinarians will provide input to the Ministry of Environment and Tourism for strengthening the requirements for holding captive animals.

1. Most animals coming into a holding facility are wild-caught and may be disease-free. Namibian farmland cheetah are considered FeLV- and FIV-free, based on results of blood tests carried out by CCF on captured cheetah over the past 5 years. There probably is a greater risk of a cheetah contracting a disease while in captivity than the risk of a cheetah introducing a disease into a facility. Even so, it is strongly recommended that newly-arrived animals be isolated in a pen separate from all other animals, where their bodily secretions, food, water, aerosols, etc. will not come into contact with each other. Also, personnel handling these animals should take precautions to ensure that contaminated materials are not carried from one cage to another. We recognise that strict quarantine procedures, as practiced in zoos and veterinary hospitals, are not really feasible in most situations in Namibia.

2. It is very important to keep cats, dogs and domestic animals away from wild-caught animals. Any pets kept by facilities handling wild animals must be vaccinated against infectious diseases which can be transmitted to wild animals (e.g., for dogs - rabies, canine distemper, parvovirus, parainfluenza; for cats - rabies, feline leukemia, viral rhinotracheitis, calici virus and panleukopenia).

3. Animals should be examined and samples taken as indicated on the Namibian Predator Examination form (see below). A portion of the samples will be banked in the Namibian Predator Genome Resource Bank coordinated by Dr. H. Scherer.

4. Blood should be sampled for the following: corona virus (FIP); FeLV; and FIV. The most important is FIP; an animal with any titre should not be moved and one of the following veterinarians should be contacted to decide measures to be taken: Dr. H. Scherer or Dr. M. Jago. Test results can be obtained quickly through Golden Vet Lab in Johannesburg, South Africa. FeLV and FIV tests, which must be done using Western Blot for monitoring/research purposes, can be done later through the CCF. Serum for these tests can be sent to Dr. H. Scherer. If an animal is to be moved out of Namibia, the CITE-Combo test for FIV can be quickly used, but it is not reliable for a definitive diagnosis.

ID# ____/______/____ ** *species ID no. initials*

NAMIBIAN PREDATOR EXAMINATION

Date: (D/M/Y)__________ 174
Sex: ☐ M ☐ F
Weight_____☐ kg ☐ lb

Farmer's Name: ______________________
Farm Name: ______________________ Farm Number__________

REGION WHERE CAUGHT ☐ A. Gobabis ☐ B. Grootfontein ☐ C. Karabib ☐ D. Okahandja ☐ E. Omaruru ☐ F. Otjiwarongo ☐ G. Outjo ☐ H. Windhoek ☑ I. Unknown ☐ J. Other ______________

CAPTURE DATA
Date of Capture (D/M/Y): __________ ☐ First Capture ☐ Re-capture ☐ Re-exam ☐ Permanent Captive
Number of days captive: ☐ 1 (catch day, 1st 24 hrs.) ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ Other ______________
(If exact day is not known for a long-term captive, then use first day of the month caught.)
Describe Capture Area: ______________________
Why Captured: ______________________
Other Animals Captured at Same Time (give ID#'s if known): ______________________
Group Size in Wild: ______________

HOLDING FACILITY:
☐ 1. Good to excellent (>25X 40 m) ☐ 2. Fair (<25X40 m, but >2.5X2 m) ☐ 3. Capture cage (or <2.5X2 m)

DEGREE OF HUMAN CONTACT:
☐ 1. Little (fed 1Xday, held away from humans with adequate privacy)
☐ 2. High (exposure in addition to feeding, and/or housed near human activity or other animals)

HAND-RAISED
☐ Yes
☐ No

DIET
A. Meat: ☐ None ☐ < 1.5 kg/day/female; <2.0 kg/day/male ☐ 1.5 kg/day/female; 2.0 kg/day/male
B. Calcium Source (supplement, milk or bone): ☐ None ☐ _____ mg/kg/day, Product Name: ______________
C. Other dietary components: Type: ______________ Amount/day: ______________
Last time fed: ☐ < 8 hrs ago ☐ 8-24 hrs ago ☐ 24-48 hrs ago ☐ > 48 hrs ago

APPROX. AGE ☐ 0-6 mo. ☐ >6-12 mo. ☐ >12-18 mo. ☐ >18mo.-2.5 yr. ☐ >2.5 - 4 yr. ☐ >4 - 8 yr. ☐ 8 - 12 yr. ☐ > 12 yrs

PHYSICAL STATUS
☐ 1. Excellent (robust, good hair coat) ☐ 2. Excellent with capture trauma
☐ 3. Good (no specific problem, but not robust)
☐ 4. Fair (poor hair coat, sores, abscesses, urine/faeces scald, other medical problems)
☐ 5. Poor (severe medical problems, questionable survival)

BODY CONDITION
☐ 1. Obese/Fat
☐ 2. Well Muscled/Lean
☐ 3. Abnormally Thin
☐ 4. Emaciated

HEALTH EXAM
Demeanor: ☐ Depressed ☐ Alert ☐ Aggressive
Hydration: ☐ Well-hydrated ☐ Dehydrated, %______
☐ Cage/Capture Trauma Wounds ☐ Lacerations ☐ Fractures ☐ Punctures ☐ Bite Wounds
describe (indicate self trauma or management-induced trauma):______________________

Coat Condition: ☐ Good ☐ Fair ☐ Poor, comment: ______________________
Hair Loss (areas and extent): ______________________
Skin Condition: ☐ Good ☐ Warts ☐ Abscesses ☐ Dermatitis, comment: ______________________
Claw Condition: ☐ Good ☐ Broken, describe: ______________________
Pad Condition: ☐ Good ☐ Injured, describe: ______________________
Eye Condition: ☐ Normal ☐ Abnormal, comment: ______________________
Ear Conditon: ☐ Normal ☐ Abnormal, comment: ______________________
Teeth/Gum Condition (indicate crowded incisors): ______________________
Respiratory System: ______________________
Digestive System: ______________________
Nervous System: ______________________
Cardiovascular System: ______________________
Ectoparasites: ☐ Cheetah Flies ☐ Lice ☐ Ticks, comment: ______________________
Vaccination History (indicate killed or MLV, and date):______________________

IDENTIFICATION (Give ID Number): Ear Tag:__________ (☐ Metal ☐ Plastic) Tattoo:__________
Transponder:__________ Radio Collar:__________ Other Marks, Notches, Scars (describe):
____

(Anaesthesia/Drugs, Samples and Lab Results on Back)

ID# ____/________/______ **
species *ID no.* *initials*

ANAESTHETICS/DRUGS GIVEN

DRUG	DOSE	ROUTE	EFFECT	COMMENTS

SIGNIFICANT LAB RESULTS AND INTERPRETATIONS

ADDITIONAL COMMENTS

SAMPLES

MINIMAL REQUESTED SAMPLES

BLOOD: 20 ml clotted (red top) separate serum; 10 ml clotted (red top) frozen whole; 2 X 10 ml heparinized (green top) separate plasma; 4 ml EDTA, 6 methanol-fixed smears; 10 ml whole blood (red top) frozen
FAECES: Frozen sample and 2 formalin-fixed smears
HAIR: Pulled out by roots with follicles, fill one film canister or similar container
SEMEN: Please contact Cheetah Conservation Fund for collection of semen

Lab Work Requested: ☐ Chemistry ☐ WBC ☐ Serology, type ______________________
☐ Faecal ☐ Skin Scrape ☐ Other: ______________________
Samples Banked: ☐ Serum ☐ Plasma ☐ Other ____________ Banking Location: ____________

LABORATORIES FOR STANDARDISED TESTING

Golden Vet Lab in Johannesburg- General Medical Profile and FIP (send 2 ml serum, 2 fixed smears)
Other Tests coordinated by Namibian Predator Genome Resource Bank

**CODES FOR ID#

Species (Identification Codes): AJU-Cheetah, PL-Lion. PPA-Leopard, HB-Brown Hyaena, CC-Spotted Hyaena, FC-Caracal, FL-African Wild Cat, FS-Serval, FN-Black Footed Cat.
ID No.: Four digit identification number assigned to this animal
Initials: Three initials of clinic, organization or clinician

NAMIBIAN
PREDATOR NECROPSY PROTOCOL

ID# ____/______/____ ** SPECIES COMMON NAME ________________
species *ID no.* *initials*

FARMER/OWNER NAME ________________________________
FARM NAME ______________________ FARM NUMBER ________
MAILING ADDRESS ________________________________
TELEPHONE ____________________ FAX ____________________

SEX: ☐ M ☐ F APPROX AGE or DATE OF BIRTH (D/M/Y) __________WEIGHT ________ kg
PRODUCED OFFSPRING? ☐Y ☐N . Unknown
IF CAPTIVE: 1. HOUSED: ☐ Single ☐ In Group ☐ With Opposite Sex ☐ With Same Sex
2. ☐ Wild Caught, date of Capture ____________ ☐ Captive Born
3. Diet ________________________________
IDENTIFICATION (Give ID Number): Ear Tag __________(☐ Metal ☐ Plastic) Tattoo__________
Transponder ____________ Radio Collar ____________ Other Marks, Notches, Scars ____________

DATE OF DEATH ________________ DATE OF NECROPSY (D/M/Y) ________________
CIRCUMSTANCES OF DEATH________________________________

GROSS EXAM PERFORMED BY: ____________________ Title ________________
Address ________________________________
Telephone ____________________ Fax ________________

HISTOPATHOLOGY PERFORMED BY: ____________________ Title ________________
Address ________________________________
Telephone ____________________ Fax ________________

GROSS EXAMINATION WORKSHEET

GENERAL CONDITION (Nutritional condition, physical condition)
MUSCULOSKELETAL SYSTEM (Bones, joints, muscles)
BODY CAVITIES (Fat stores, abnormal fluids)
HEMOLYMPHATIC (Spleen, lymph nodes, thymus)

****ID #:**
Species (Identification Codes): AJU-Cheetah, PL-Lion. PPA-Leopard, HB-Brown Hyaena, CC-Spotted Hyaena, FC-Caracal, FL-African Wild Cat, FS-Serval, FN-Black Footed Cat.
ID No.: Four digit identification number assigned to this animal
Initials: Three initials of clinic, organization or clinician

RESPIRATORY SYSTEM (Nasal cavity, larynx, trachea, lungs, regional lymph nodes)
CARDIOVASCULAR SYSTEM (Heart, pericardium, great vessels)
DIGESTIVE SYSTEM (Mouth, teeth, esophagus, stomach, intestines, liver, pancreas, mesenteric lymph nodes)
URINARY SYSTEM (Kidneys, ureters, urinary bladder, urethra)
REPRODUCTIVE SYSTEM (Testis/ovary, uterus, vagina, penis, prepuce, accessory glands, mammary glands)
ENDOCRINE SYSTEM (Adrenals, thyroid, parathyroids, pituitary)
NERVOUS SYSTEM (Brain, spinal cord, peripheral nerves)
SENSORY ORGANS (Eyes, ears)
PRELIMINARY DIAGNOSIS
LABORATORY STUDIES (List samples submitted and attach results, if available)

ID# _____/_______/_____ ** **TISSUE CHECKLIST**

species *ID no.* *initials*

FIXED TISSUES

Take duplicate sets of tissues, one set for the National Pathologist and one for the International Pathologist. Preserve the following tissues and any lesions in 10% buffered formalin at a rate of 1 part tissue to 10 parts formalin. Tissues should be no thicker than 1 cm.

- ☐ Salivary gland
- ☐ Tongue
- ☐ Lung
- ☐ Trachea
- ☐ Thyroid/parathyroids
- ☐ Lymph nodes
- ☐ Thymus
- ☐ Heart
- ☐ Liver - one section from each lobe
- ☐ Spleen
- ☐ Stomach -multiple sections from cardia, fundus (body) and pylorus
- ☐ Small intestines
- ☐ Large intestines
- ☐ Pancreas including central ducts
- ☐ Adrenal
- ☐ Kidney - cortex and medulla from each kidney
- ☐ Urinary bladder
- ☐ Testis/ovary
- ☐ Uterus
- ☐ Eye
- ☐ Brain
- ☐ Spinal cord (if neurologic disease)
- ☐ Diaphragm and skeletal muscle
- ☐ Rib or 1/2 femur with marrow
- ☐ Skin

FROZEN TISSUE IF POSSIBLE

If poisoning or toxicity is suspected, please store 10 g of liver, brain, and kidney, plus antemortem serum and plasma at - 70º C.

ADDITIONAL TISSUES/SAMPLES IF AVAILABLE

- ☐ Hair (pulled out by the roots-one film canister full)
- ☐ Faeces (Frozen)
- ☐ Faeces (Smear, fixed in 10% formalin)
- ☐ Whole Blood (20 ml frozen)
- ☐ Blood Smears (four fixed in methanol)
- ☐ Skin (approx. 5 cm square, dried in paper envelope, not fixed or frozen)
- ☐ ***Testes if animal is freshly dead or euthanized: collect whole testicles including epididymis and place in saline soaked paper towels and place in refrigerator, not directly on ice. Call Cheetah Conservation Fund immediately to arrange transport.

NEONATAL NECROPSY PROTOCOL

Please follow the adult protocol in addition to the following:

- ☐ Fix umbilical stump and surrounding tissues
- ☐ Examine for malformations (cleft palate, deformed limbs)
- ☐ Assess hydration (tissue moistness) and evidence of nursing (milk in stomach)
- ☐ Determine if breathing occurred (lungs float in formalin)

Please send samples and this checklist to one of the following Namibian Predator Genome Resource Banks:

Dr. H. Scherer	Dr. M. Jago	Cheetah Conservation Fund
Otjiwarongo	Otjiwarongo Vet Clinic	Otjiwarongo
Phone: 0651-2801	Phone: 0651-3242	Phone/Fax: 0658-11812
Fax: 0651-2823	Fax: 0651-4382	Fax: 0651-3607

RECOMMENDED TISSUE SAMPLING PROCEDURES

Note: Do not wash any samples. Remove large blood clots or ingesta, etc. by hand.

ADRENAL GLANDS: Entire gland with transverse incision

BRAIN: Sliced longitudinally along the midline submit all

EYE: Leave intact

FECES: Preferably collect from descending colon

GASTROINTESTINAL TRACT: 3 cm long section of esophagus, stomach (cardia, undus, pylorus), duodenum, jejunum, ileaum, cecum, colon, and omentum. Open carefully along the long axis. Do not wash, shake off exess digesta.

HAIR: Pulled out with roots and follicles (pack a 16 x 50 mm, i.e. 35 mm film canister)

HEART: Longitudinal section including atrium, ventricle and valves from both right and left heart.

KIDNEYS: Section from both kidneys (cortex, medulla, and pelvis).

LIVER: Sections from 3 lobes with capsule and gall bladder.

LONG BONE: Submit ½ of a femur.

LUNGS: Sections from several lobes including a major bronchus.

LYMPH NODES: Cervical, anterior mediastinal, bronchial, mesenteric, and lumbar with a transverse cut.

PANCREAS: Representative sections for two areas.

REPRODUCTIVE TRACT: Entire uterus and ovaries with longitudinal cut in to lumen. Entire testis with transverse cut. Entire prostate with transverse cut.

SKELETAL MUSCLE: Cross Section of thigh muscles.

SKIN: Full thickness of abdominal skin and lip.

SPINAL CORD: Sections from cervical, thoracic and lumbar cord.

SPLEEN: Cross sections including capsule.

THYMUS: Representative section.

THYROID/PARATHYROIDS AND PITUITARY GLAND: Leave glands intact.

TONGUE: Cross section near tip including both mucosal surfaces.

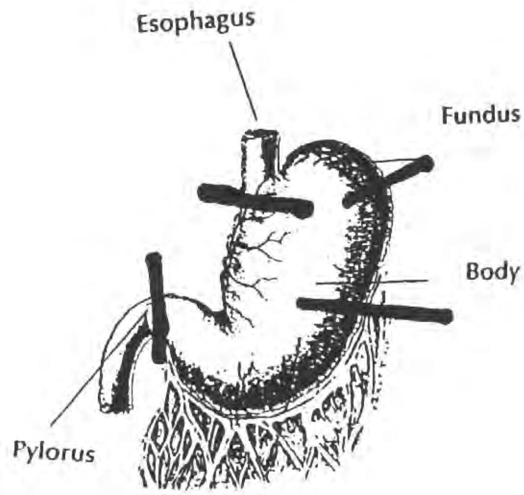
URINARY BLADDER/URETER/URETHRA: Cross section of bladder and 2 cm sections of tubular structures.

CHEETAH NECROPSY PROTOCOL

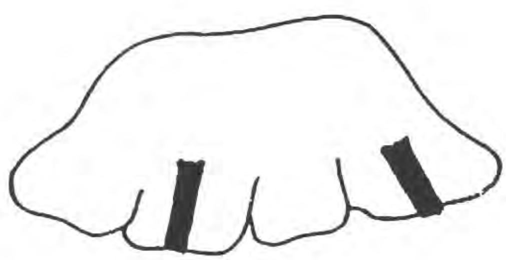
All animals should be laid on their right side. The carcass should be opened on the underside with a cut running the length of the body. The cut should start at the chin and ago all the way to the rectum. The cut should be along the midline of the body, not to one side. Once the skin and muscles of the body wall are opened up, you will be looking down on the rib cage and the intestines. If you gently lift the intestines and associated tissues and move them aside (without cutting anything), you will see the stomach and the liver, which lie against the base of the rib cage. You will also need to open the rib cage to expose the heart and lungs. Take the tissue samples as illustrated by the heavy black lines.

Essential:

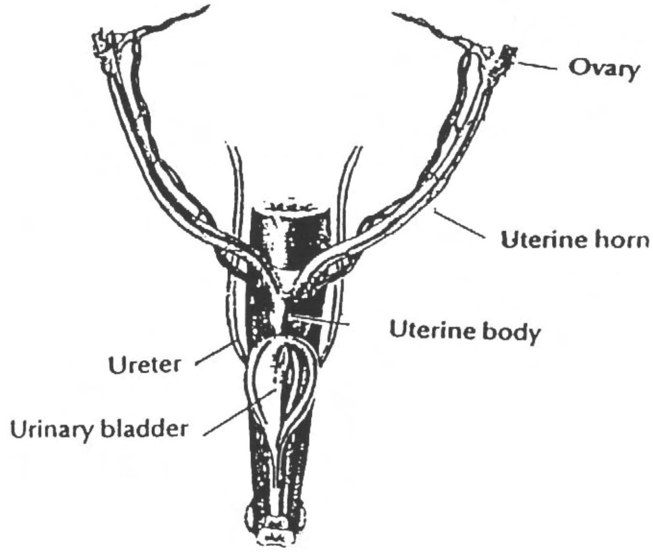
1. Stomach – Full thickness sections from the fundus/body, the pylorus, and the region ear the entrance of the esophagus.



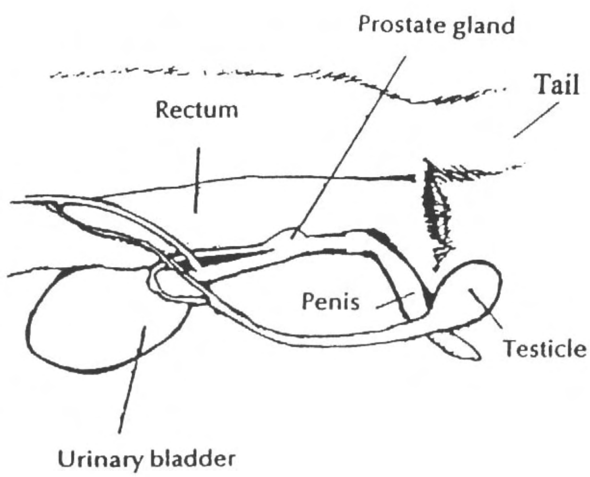
2. Liver – Sections from three different lobes. Include outer sheath.



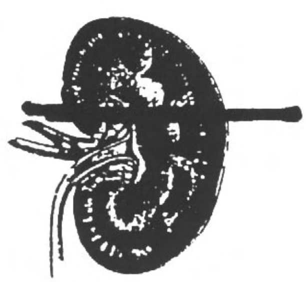
3. Reproductive Tract – Female: As you look down on the animal the body of the uterus lies on top of the rectum. Follow it up along the horns of the uterus to the ovaries. Take the entire uterus (body and horn) and ovaries. Make a longitudinal cut through the body.



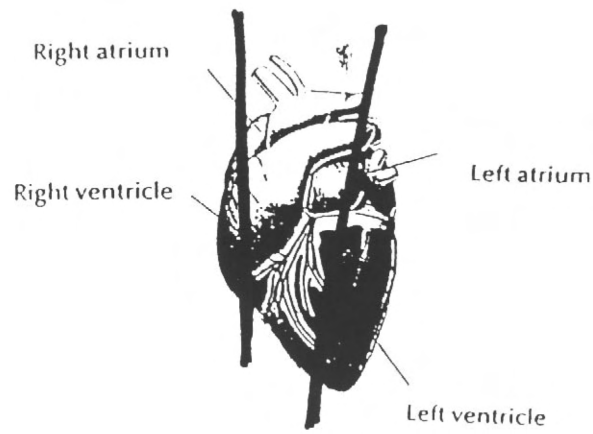
Male: Enitre testis with associated structures and prostate gland.



4. Kidney – The kidneys are found deep, against the animal's back. Take a full thickness section across both kidneys as illustrated.



<u>5. Heart –</u> Two full thickness sections, one through the right atrium and ventricle and one through left atrium and ventricle.

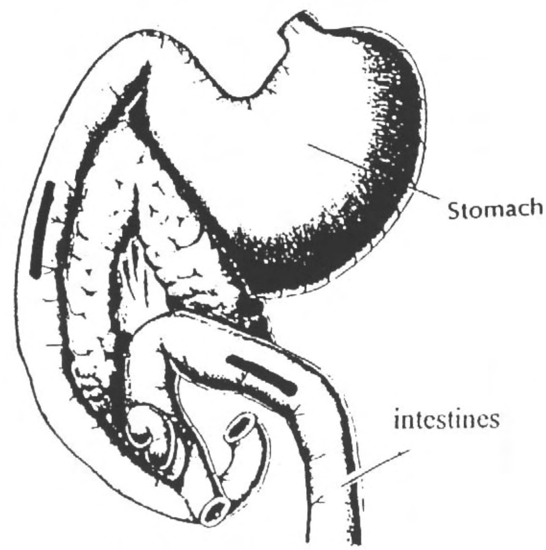


<u>6. Muscle -</u> Section through thigh muscles.

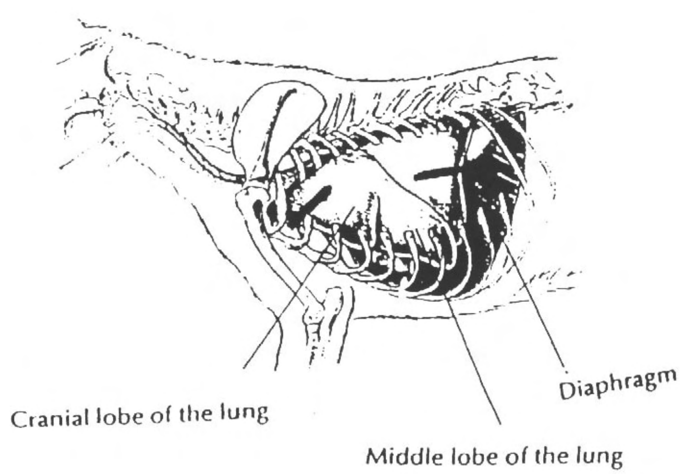
<u>7. Skin –</u> Full thickness section through skin on abdomen.

Nonessential:

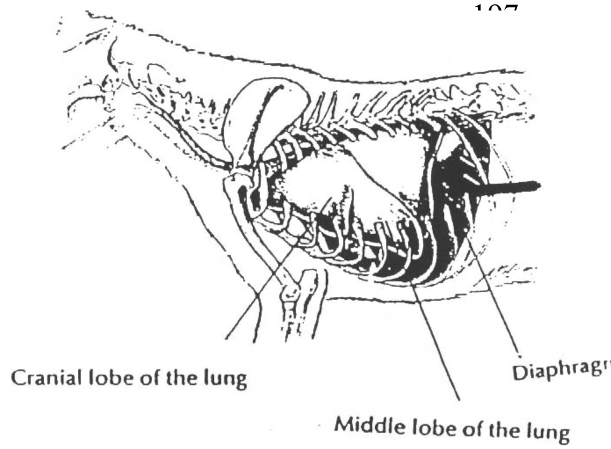
1. Intestines – Follow the intestines from the stomach all the way to the rectum. Open along long axis and take several 3 cm long sections along the length of the intestines as illustrated.



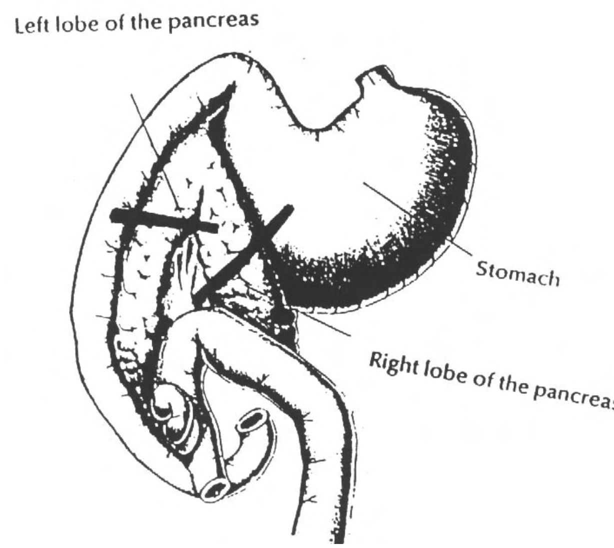
<u>2. Lungs –</u> Sections from several lobes.



3. Diaphragm – The diaphragm is the large sheet of muscle that lies under the ribs and separates the chest from the belly. Take a full thickness section.

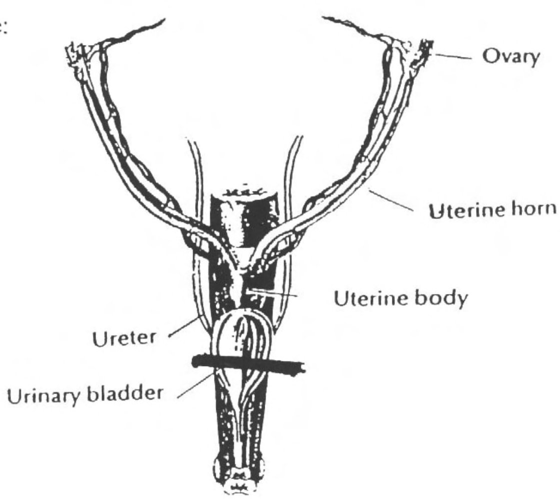


4. Pancreas – The pancreas lies alongside the beginning part of the intestines. It is a pale organ, generally found on the right side of the animal's body. Take two sections from different areas.

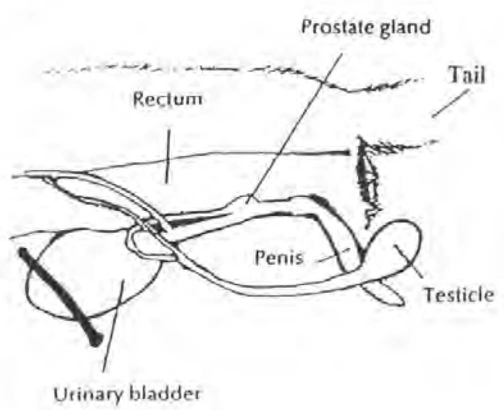


5. Urinary bladder – Full thickness section through the bladder.

Female:



Male:



6. Tongue – Full thickness section near the tip.

7. Spleen – The spleen is a dark red organ, usually found on the animal's left side near the stomach. Take a section that includes the outer sheath.

POPULATION AND HABITAT VIABILITY ASSESSMENT FOR THE NAMIBIAN CHEETAH (*Acinonyx jubatus*) AND LION *(Panthera leo)*

11-16 February 1996
Otjiwarongo, Namibia

Workshop Report
February 1997

SECTION 5

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SECTION 6

VORTEX TECHNICAL REFERENCE

Wildl. Res., 1993, **20**, 45–65

Appendix IV.

VORTEX: A Computer Simulation Model for Population Viability Analysis

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Abstract

Population Viability Analysis (PVA) is the estimation of extinction probabilities by analyses that incorporate identifiable threats to population survival into models of the extinction process. Extrinsic forces, such as habitat loss, over-harvesting, and competition or predation by introduced species, often lead to population decline. Although the traditional methods of wildlife ecology can reveal such deterministic trends, random fluctuations that increase as populations become smaller can lead to extinction even of populations that have, on average, positive population growth when below carrying capacity. Computer simulation modelling provides a tool for exploring the viability of populations subjected to many complex, interacting deterministic and random processes. One such simulation model, VORTEX, has been used extensively by the Captive Breeding Specialist Group (Species Survival Commission, IUCN), by wildlife agencies, and by university classes. The algorithms, structure, assumptions and applications of VORTEX are described in this paper.

VORTEX models population processes as discrete, sequential events, with probabilistic outcomes. VORTEX simulates birth and death processes and the transmission of genes through the generations by generating random numbers to determine whether each animal lives or dies, to determine the number of progeny produced by each female each year, and to determine which of the two alleles at a genetic locus are transmitted from each parent to each offspring. Fecundity is assumed to be independent of age after an animal reaches reproductive age. Mortality rates are specified for each pre-reproductive age–sex class and for reproductive-age animals. Inbreeding depression is modelled as a decrease in viability in inbred animals.

The user has the option of modelling density dependence in reproductive rates. As a simple model of density dependence in survival, a carrying capacity is imposed by a probabilistic truncation of each age class if the population size exceeds the specified carrying capacity. VORTEX can model linear trends in the carrying capacity. VORTEX models environmental variation by sampling birth rates, death rates, and the carrying capacity from binomial or normal distributions. Catastrophes are modelled as sporadic random events that reduce survival and reproduction for one year. VORTEX also allows the user to supplement or harvest the population, and multiple subpopulations can be tracked, with user-specified migration among the units.

VORTEX outputs summary statistics on population growth rates, the probability of population extinction, the time to extinction, and the mean size and genetic variation in extant populations.

VORTEX necessarily makes many assumptions. The model it incorporates is most applicable to species with low fecundity and long lifespans, such as mammals, birds and reptiles. It integrates the interacting effects of many of the deterministic and stochastic processes that have an impact on the viability of small populations, providing opportunity for more complete analysis than is possible by other techniques. PVA by simulation modelling is an important tool for identifying populations at risk of extinction, determining the urgency of action, and evaluating options for management.

Introduction

Many wildlife populations that were once widespread, numerous, and occupying contiguous habitat, have been reduced to one or more small, isolated populations. The causes of the original decline are often obvious, deterministic forces, such as over-harvesting,

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habitat destruction, and competition or predation from invasive introduced species. Even if the original causes of decline are removed, a small isolated population is vulnerable to additional forces, intrinsic to the dynamics of small populations, which may drive the population to extinction (Shaffer 1981; Soulé 1987; Clark and Seebeck 1990). Of particular impact on small populations are stochastic processes. With the exception of aging, virtually all events in the life of an organism are stochastic. Mating, reproduction, gene transmission between generations, migration, disease and predation can be described by probability distributions, with individual occurrences being sampled from these distributions. Small samples display high variance around the mean, so the fates of small wildlife populations are often determined more by random chance than by the mean birth and death rates that reflect adaptations to their environment.

Although many processes affecting small populations are intrinsically indeterminate, the average long-term fate of a population and the variance around the expectation can be studied with computer simulation models. The use of simulation modelling, often in conjunction with other techniques, to explore the dynamics of small populations has been termed Population Viability Analysis (PVA). PVA has been increasingly used to help guide management of threatened species. The Resource Assessment Commission of Australia (1991) recently recommended that 'estimates of the size of viable populations and the risks of extinction under multiple-use forestry practices be an essential part of conservation planning'. Lindenmayer *et al.* (1993) describe the use of computer modelling for PVA, and discuss the strengths and weaknesses of the approach as a tool for wildlife management.

In this paper, I present the PVA program VORTEX and describe its structure, assumptions and capabilities. VORTEX is perhaps the most widely used PVA simulation program, and there are numerous examples of its application in Australia, the United States of America and elsewhere.

The Dynamics of Small Populations

The stochastic processes that have an impact on populations have been usefully categorised into demographic stochasticity, environmental variation, catastrophic events and genetic drift (Shaffer 1981). Demographic stochasticity is the random fluctuation in the observed birth rate, death rate and sex ratio of a population even if the probabilities of birth and death remain constant. On the assumption that births and deaths and sex determination are stochastic sampling processes, the annual variations in numbers that are born, die, and are of each sex can be specified from statistical theory and would follow binomial distributions. Such demographic stochasticity will be important to population viability only in populations that are smaller than a few tens of animals (Goodman 1987), in which cases the annual frequencies of birth and death events and the sex ratios can deviate far from the means. The distribution of annual adult survival rates observed in the remnant population of whooping cranes (*Grus americana*) (Mirande *et al.* 1993) is shown in Fig. 1. The innermost curve approximates the binomial distribution that describes the demographic stochasticity expected when the probability of survival is 92·7% (mean of 45 non-outlier years).

Environmental variation is the fluctuation in the probabilities of birth and death that results from fluctuations in the environment. Weather, the prevalence of enzootic disease, the abundances of prey and predators, and the availability of nest sites or other required microhabitats can all vary, randomly or cyclically, over time. The second narrowest curve on Fig. 1 shows a normal distribution that statistically fits the observed frequency histogram of crane survival in non-outlier years. The difference between this curve and the narrower distribution describing demographic variation must be accounted for by environmental variation in the probability of adult survival.

Catastrophic variation is the extreme of environmental variation, but for both methodological and conceptual reasons rare catastrophic events are analysed separately from the more typical annual or seasonal fluctuations. Catastrophes such as epidemic disease,

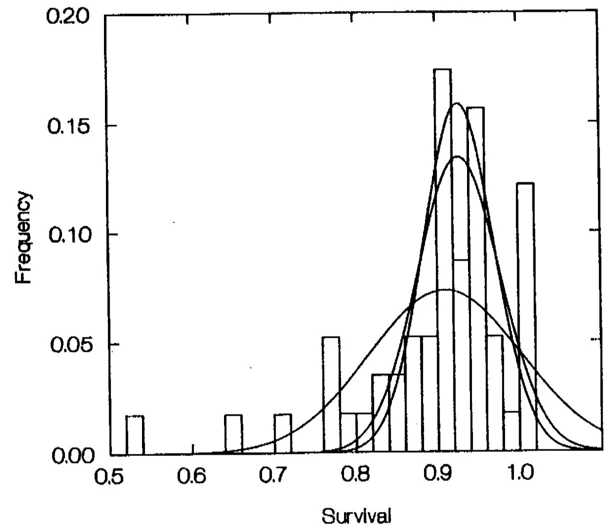

Fig. 1. Frequency histogram of the proportion of whooping cranes surviving each year, 1938–90. The broadest curve is the normal distribution that most closely fits the overall histogram. Statistically, this curve fits the data poorly. The second highest and second broadest curve is the normal distribution that most closely fits the histogram, excluding the five leftmost bars (7 outlier 'catastrophe' years). The narrowest and tallest curve is the normal approximation to the binomial distribution expected from demographic stochasticity. The difference between the tallest and second tallest curves is the variation in annual survival due to environmental variation.

hurricanes, large-scale fires, and floods are outliers in the distribution of environmental variation (e.g. five leftmost bars on Fig. 1). As a result, they have quantitatively and sometimes qualitatively different impacts on wildlife populations. (A forest fire is not just a very hot day.) Such events often precipitate the final decline to extinction (Simberloff 1986, 1988). For example, one of two populations of whooping crane was decimated by a hurricane in 1940 and soon after went extinct (Doughty 1989). The only remaining population of the black-footed ferret (*Mustela nigripes*) was being eliminated by an outbreak of distemper when the last 18 ferrets were captured (Clark 1989).

Genetic drift is the cumulative and non-adaptive fluctuation in allele frequencies resulting from the random sampling of genes in each generation. This can impede the recovery or accelerate the decline of wildlife populations for several reasons (Lacy 1993). Inbreeding, not strictly a component of genetic drift but correlated with it in small populations, has been documented to cause loss of fitness in a wide variety of species, including virtually all sexually reproducing animals in which the effects of inbreeding have been carefully studied (Wright 1977; Falconer 1981; O'Brien and Evermann 1988; Ralls *et al.* 1988; Lacy *et al.* 1993). Even if the immediate loss of fitness of inbred individuals is not large, the loss of genetic variation that results from genetic drift may reduce the ability of a population to adapt to future changes in the environment (Fisher 1958; Robertson 1960; Selander 1983).

Thus, the effects of genetic drift and consequent loss of genetic variation in individuals and populations have a negative impact on demographic rates and increase susceptibility to environmental perturbations and catastrophes. Reduced population growth and greater fluctuations in numbers in turn accelerate genetic drift (Crow and Kimura 1970). These synergistic destabilising effects of stochastic process on small populations of wildlife have been described as an 'extinction vortex' (Gilpin and Soulé 1986). The size below which a population is likely to be drawn into an extinction vortex can be considered a 'minimum viable population' (MVP) (Seal and Lacy 1989), although Shaffer (1981) first defined a MVP more stringently as a population that has a 99% probability of persistence for 1000 years. The estimation of MVPs or, more generally, the investigation of the probability of extinction constitutes PVA (Gilpin and Soulé 1986; Gilpin 1989; Shaffer 1990).

Methods for Analysing Population Viability

An understanding of the multiple, interacting forces that contribute to extinction vortices is a prerequisite for the study of extinction–recolonisation dynamics in natural populations inhabiting patchy environments (Gilpin 1987), the management of small populations (Clark and Seebeck 1990), and the conservation of threatened wildlife (Shaffer 1981, 1990; Soulé 1987; Mace and Lande 1991). Because demographic and genetic processes in small populations are inherently unpredictable, the expected fates of wildlife populations can be described in terms of probability distributions of population size, time to extinction, and genetic variation. These distributions can be obtained in any of three ways: from analytical models, from empirical observation of the fates of populations of varying size, or from simulation models.

As the processes determining the dynamics of populations are multiple and complex, there are few analytical formulae for describing the probability distributions (e.g. Goodman 1987; Lande 1988; Burgmann and Gerard 1990). These models have incorporated only few of the threatening processes. No analytical model exists, for example, to describe the combined effect of demographic stochasticity and loss of genetic variation on the probability of population persistence.

A few studies of wildlife populations have provided empirical data on the relationship between population size and probability of extinction (e.g. Belovsky 1987; Berger 1990; Thomas 1990), but presently only order-of-magnitude estimates can be provided for MVPs of vertebrates (Shaffer 1987). Threatened species are, by their rarity, unavailable and inappropriate for the experimental manipulation of population sizes and long-term monitoring of undisturbed fates that would be necessary for precise empirical measurement of MVPs. Retrospective analyses will be possible in some cases, but the function relating extinction probability to population size will differ among species, localities and times (Lindenmayer *et al.* 1993).

Modelling the Dynamics of Small Populations

Because of the lack of adequate empirical data or theoretical and analytical models to allow prediction of the dynamics of populations of threatened species, various biologists have turned to Monte Carlo computer simulation techniques for PVA. By randomly sampling from defined probability distributions, computer programs can simulate the multiple, interacting events that occur during the lives of organisms and that cumulatively determine the fates of populations. The focus is on detailed and explicit modelling of the forces impinging on a given population, place, and time of interest, rather than on delineation of rules (which may not exist) that apply generally to most wildlife populations. Computer programs available to PVA include SPGPC (Grier 1980*a*, 1980*b*), GAPPS (Harris *et al.* 1986), RAMAS (Ferson and Akçakaya 1989; Akçakaya and Ferson 1990; Ferson 1990), FORPOP (Possingham *et al.* 1991), ALEX (Possingham *et al.* 1992), and SIMPOP (Lacy *et al.* 1989; Lacy and Clark 1990) and its descendant VORTEX.

SIMPOP was developed in 1989 by converting the algorithms of the program SPGPC (written by James W. Grier of North Dakota State University) from BASIC to the C programming language. SIMPOP was used first in a PVA workshop organised by the Species Survival Commission's Captive Breeding Specialist Group (IUCN), the United States Fish and Wildlife Service, and the Puerto Rico Department of Natural Resources to assist in planning and assessing recovery efforts for the Puerto Rican crested toad (*Peltophryne lemur*). SIMPOP was subsequently used in PVA modelling of other species threatened with extinction, undergoing modification with each application to allow incorporation of additional threatening processes. The simulation program was renamed VORTEX (in reference to the extinction vortex) when the capability of modelling genetic processes was implemented in 1989. In 1990, a version allowing modelling of multiple populations was briefly named VORTICES. The only version still supported, with all capabilities of each previous version, is VORTEX Version 5.1.

VORTEX has been used in PVA to help guide conservation and management of many species, including the Puerto Rican parrot (*Amazona vittata*) (Lacy *et al.* 1989), the Javan rhinoceros (*Rhinoceros sondaicus*) (Seal and Foose 1989), the Florida panther (*Felis concolor coryi*) (Seal and Lacy 1989), the eastern barred bandicoot (*Perameles gunnii*) (Lacy and Clark 1990; Maguire *et al.* 1990), the lion tamarins (*Leontopithecus rosalia* ssp.) (Seal *et al.* 1990), the brush-tailed rock-wallaby (*Petrogale penicillata penicillata*) (Hill 1991), the mountain pygmy-possum (*Burramys parvus*), Leadbeater's possum (*Gymnobelideus leadbeateri*), the long-footed potoroo (*Potorous longipes*), the orange-bellied parrot (*Neophema chrysogaster*) and the helmeted honeyeater (*Lichenostomus melanops cassidix*) (Clark *et al.* 1991), the whooping crane (*Grus americana*) (Mirande *et al.* 1993), the Tana River crested mangabey (*Cercocebus galeritus galeritus*) and the Tana River red colobus (*Colobus badius rufomitratus*) (Seal *et al.* 1991), and the black rhinoceros (*Diceros bicornis*) (Foose *et al.* 1992). In some of these PVAs, modelling with VORTEX has made clear the insufficiency of past management plans to secure the future of the species, and alternative strategies were proposed, assessed and implemented. For example, the multiple threats to the Florida panther in its existing habitat were recognised as probably insurmountable, and a captive breeding effort has been initiated for the purpose of securing the gene pool and providing animals for release in areas of former habitat. PVA modelling with VORTEX has often identified a single threat to which a species is particularly vulnerable. The small but growing population of Puerto Rican parrots was assessed to be secure, except for the risk of population decimation by hurricane. Recommendations were made to make available secure shelter for captive parrots and to move some of the birds to a site distant from the wild flock, in order to minimise the damage that could occur in a catastrophic storm. These recommended actions were only partly implemented when, in late 1989, a hurricane killed many of the wild parrots. The remaining population of about 350 Tana River red colobus were determined by PVA to be so fragmented that demographic and genetic processes within the 10 subpopulations destabilised population dynamics. Creation of habitat corridors may be necessary to prevent extinction of the taxon. In some cases, PVA modelling has been reassuring to managers: analysis of black rhinos in Kenya indicated that many of the populations within sanctuaries were recovering steadily. Some could soon be used to provide animals for re-establishment or supplementation of populations previously eliminated by poaching. For some species, available data were insufficient to allow definitive PVA with VORTEX. In such cases, the attempt at PVA modelling has made apparent the need for more data on population trends and processes, thereby helping to justify and guide research efforts.

Description of VORTEX

Overview

The VORTEX computer simulation model is a Monte Carlo simulation of the effects of deterministic forces, as well as demographic, environmental and genetic stochastic events, on wildlife populations. VORTEX models population dynamics as discrete, sequential events that occur according to probabilities that are random variables, following user-specified distributions. The input parameters used by VORTEX are summarised in the first part of the sample output given in the Appendix.

VORTEX simulates a population by stepping through a series of events that describe an annual cycle of a typical sexually reproducing, diploid organism: mate selection, reproduction, mortality, increment of age by one year, migration among populations, removals, supplementation, and then truncation (if necessary) to the carrying capacity. The program was designed to model long-lived species with low fecundity, such as mammals, birds and reptiles. Although it could and has been used in modelling highly fecund vertebrates and invertebrates, it is awkward to use in such cases as it requires complete specification of the percentage of females producing each possible clutch size. Moreover, computer memory limitations often hamper such analyses. Although VORTEX iterates life events on an annual cycle, a user could model 'years' that are other than 12 months' duration. The simulation of the population is itself iterated to reveal the distribution of fates that the population might experience.

Demographic Stochasticity

VORTEX models demographic stochasticity by determining the occurrence of probabilistic events such as reproduction, litter size, sex determination and death with a pseudo-random number generator. The probabilities of mortality and reproduction are sex-specific and pre-determined for each age class up to the age of breeding. It is assumed that reproduction and survival probabilities remain constant from the age of first breeding until a specified upper limit to age is reached. Sex ratio at birth is modelled with a user-specified constant probability of an offspring being male. For each life event, if the random value sampled from the uniform 0–1 distribution falls below the probability for that year, the event is deemed to have occurred, thereby simulating a binomial process.

The source code used to generate random numbers uniformly distributed between 0 and 1 was obtained from Maier (1991), according to the algorithm of Kirkpatrick and Stoll (1981). Random deviates from binomial distributions, with mean p and standard deviation s, are obtained by first determining the integral number of binomial trials, N, that would produce the value of s closest to the specified value, according to

$$N = p(1-p)/s^2 .$$

N binomial trials are then simulated by sampling from the uniform 0–1 distribution to obtain the desired result, the frequency or proportion of successes. If the value of N determined for a desired binomial distribution is larger than 25, a normal approximation is used in place of the binomial distribution. This normal approximation must be truncated at 0 and at 1 to allow use in defining probabilities, although, with such large values of N, s is small relative to p and the truncation would be invoked only rarely. To avoid introducing bias with this truncation, the normal approximation to the binomial (when used) is truncated symmetrically around the mean. The algorithm for generating random numbers from a unit normal distribution follows Latour (1986).

VORTEX can model monogamous or polygamous mating systems. In a monogamous system, a relative scarcity of breeding males may limit reproduction by females. In polygamous or monogamous models, the user can specify the proportion of the adult males in the breeding pool. Males are randomly reassigned to the breeding pool each year of the simulation, and all males in the breeding pool have an equal chance of siring offspring.

The 'carrying capacity', or the upper limit for population size within a habitat, must be specified by the user. VORTEX imposes the carrying capacity via a probabilistic truncation whenever the population exceeds the carrying capacity. Each animal in the population has an equal probability of being removed by this truncation.

Environmental Variation

VORTEX can model annual fluctuations in birth and death rates and in carrying capacity as might result from environmental variation. To model environmental variation, each demographic parameter is assigned a distribution with a mean and standard deviation that is specified by the user. Annual fluctuations in probabilities of reproduction and mortality are modelled as binomial distributions. Environmental variation in carrying capacity is modelled as a normal distribution. The variance across years in the frequencies of births and deaths resulting from the simulation model (and in real populations) will have two components: the demographic variation resulting from a binomial sampling around the mean for each year, and additional fluctuations due to environmental variation and catastrophes (see Fig. 1 and section on The Dynamics of Small Populations, above).

Data on annual variations in birth and death rates are important in determining the probability of extinction, as they influence population stability (Goodman 1987). Unfortunately, such field information is rarely available (but see Fig. 1). Sensitivity testing, the examination of a range of values when the precise value of a parameter is unknown, can help to identify whether the unknown parameter is important in the dynamics of a population.

Catastrophes

Catastrophes are modelled in VORTEX as random events that occur with specified probabilities. Any number of types of catastrophes can be modelled. A catastrophe will occur if a randomly generated number between zero and one is less than the probability of occurrence. Following a catastrophic event, the chances of survival and successful breeding for that simulated year are multiplied by severity factors. For example, forest fires might occur once in 50 years, on average, killing 25% of animals, and reducing breeding by survivors by 50% for the year. Such a catastrophe would be modelled as a random event with 0·02 probability of occurrence each year, and severity factors of 0·75 for survival and 0·50 for reproduction.

Genetic Processes

Genetic drift is modelled in VORTEX by simulation of the transmission of alleles at a hypothetical locus. At the beginning of the simulation, each animal is assigned two unique alleles. Each offspring is randomly assigned one of the alleles from each parent. Inbreeding depression is modelled as a loss of viability during the first year of inbred animals. The impacts of inbreeding are determined by using one of two models available within VORTEX: a Recessive Lethals model or a Heterosis model.

In the Recessive Lethals model, each founder starts with one unique recessive lethal allele and a unique, dominant non-lethal allele. This model approximates the effect of inbreeding if each individual in the starting population had one recessive lethal allele in its genome. The fact that the simulation program assumes that all the lethal alleles are at the same locus has a very minor impact on the probability that an individual will die because of homozygosity for one of the lethal alleles. In the model, homozygosity for different lethal alleles are mutually exclusive events, whereas in a multilocus model an individual could be homozygous for several lethal alleles simultaneously. By virtue of the death of individuals that are homozygous for lethal alleles, such alleles would be removed slowly by natural selection during the generations of a simulation. This reduces the genetic variation present in the population relative to the case with no inbreeding depression, but also diminishes the subsequent probability that inbred individuals will be homozygous for a lethal allele. This model gives an optimistic reflection of the impacts of inbreeding on many species, as the median number of lethal equivalents per diploid genome observed for mammalian populations is about three (Ralls *et al.* 1988).

The expression of fully recessive deleterious alleles in inbred organisms is not the only genetic mechanism that has been proposed as a cause of inbreeding depression. Some or most of the effects of inbreeding may be a consequence of superior fitness of heterozygotes (heterozygote advantage or 'heterosis'). In the Heterosis model, all homozygotes have reduced fitness compared with heterozygotes. Juvenile survival is modelled according to the logarithmic model developed by Morton *et al.* (1956):

$$\ln S = A - BF$$

in which S is survival, F is the inbreeding coefficient, A is the logarithm of survival in the absence of inbreeding, and B is a measure of the rate at which survival decreases with inbreeding. B is termed the number of 'lethal equivalents' per haploid genome. The number of lethal equivalents per diploid genome, $2B$, estimates the number of lethal alleles per individual in the population if all deleterious effects of inbreeding were due to recessive lethal alleles. A population in which inbreeding depression is one lethal equivalent per diploid genome may have one recessive lethal allele per individual (as in the Recessive Lethals model, above), it may have two recessive alleles per individual, each of which confer a 50% decrease in survival, or it may have some other combination of recessive deleterious alleles that equate in effect with one lethal allele per individual. Unlike the situation with fully recessive deleterious alleles, natural selection does not remove deleterious alleles at heterotic loci because all alleles are deleterious when homozygous and beneficial when present in heterozygous combination with other alleles. Thus, under the Heterosis model, the impact of inbreeding on survival does not diminish during repeated generations of inbreeding.

Unfortunately, for relatively few species are data available to allow estimation of the effects of inbreeding, and the magnitude of these effects varies considerably among species (Falconer 1981; Ralls *et al.* 1988; Lacy *et al.* 1993). Moreover, whether a Recessive Lethals model or a Heterosis model better describes the underlying mechanism of inbreeding depression and therefore the response to repeated generations of inbreeding is not well-known (Brewer *et al.* 1990), and could be determined empirically only from breeding studies that span many generations. Even without detailed pedigree data from which to estimate the number of lethal equivalents in a population and the underlying nature of the genetic load (recessive alleles or heterosis), applications of PVA must make assumptions about the effects of inbreeding on the population being studied. In some cases, it might be considered appropriate to assume that an inadequately studied species would respond to inbreeding in accord with the median (3·14 lethal equivalents per diploid) reported in the survey by Ralls *et al.* (1988). In other cases, there might be reason to make more optimistic assumptions (perhaps the lower quartile, 0·90 lethal equivalents), or more pessimistic assumptions (perhaps the upper quartile, 5·62 lethal equivalents).

Deterministic Processes

VORTEX can incorporate several deterministic processes. Reproduction can be specified to be density-dependent. The function relating the proportion of adult females breeding each year to the total population size is modelled as a fourth-order polynomial, which can provide a close fit to most plausible density-dependence curves. Thus, either positive population responses to low-density or negative responses (e.g. Allee effects), or more complex relationships, can be modelled.

Populations can be supplemented or harvested for any number of years in each simulation. Harvest may be culling or removal of animals for translocation to another (unmodelled) population. The numbers of additions and removals are specified according to the age and sex of animals. Trends in the carrying capacity can also be modelled in VORTEX, specified as an annual percentage change. These changes are modelled as linear, rather than geometric, increases or decreases.

Migration among Populations

VORTEX can model up to 20 populations, with possibly distinct population parameters. Each pairwise migration rate is specified as the probability of an individual moving from one population to another. This probability is independent of the age and sex. Because of between-population migration and managed supplementation, populations can be recolonised. VORTEX tracks the dynamics of local extinctions and recolonisations through the simulation.

Output

VORTEX outputs (1) probability of extinction at specified intervals (e.g., every 10 years during a 100-year simulation), (2) median time to extinction if the population went extinct in at least 50% of the simulations, (3) mean time to extinction of those simulated populations that became extinct, and (4) mean size of, and genetic variation within, extant populations (see Appendix and Lindenmayer *et al.* 1993).

Standard deviations across simulations and standard errors of the mean are reported for population size and the measures of genetic variation. Under the assumption that extinction of independently replicated populations is a binomial process, the standard error of the probability of extinction (*SE*) is reported by VORTEX as

$$SE(p) = \sqrt{[p \times (1-p)/n]}\ ,$$

in which the frequency of extinction was p over n simulated populations. Demographic and genetic statistics are calculated and reported for each subpopulation and for the metapopulation.

Availability of the VORTEX Simulation Program

VORTEX Version 5.1 is written in the C programming language and compiled with the Lattice 80286C Development System (Lattice Inc.) for use on microcomputers using the MS-DOS (Microsoft Corp.) operating system. Copies of the compiled program and a manual for its use are available for nominal distribution costs from the Captive Breeding Specialist Group (Species Survival Commission, IUCN), 12101 Johnny Cake Ridge Road, Apple Valley, Minnesota 55124, U.S.A. The program has been tested by many workers, but cannot be guaranteed to be error-free. Each user retains responsibility for ensuring that the program does what is intended for each analysis.

Sequence of Program Flow

(1) The seed for the random number generator is initialised with the number of seconds elapsed since the beginning of the 20th century.

(2) The user is prompted for input and output devices, population parameters, duration of simulation, and number of interations.

(3) The maximum allowable population size (necessary for preventing memory overflow) is calculated as

$$N_{max} = (K + 3s) \times (1 + L)$$

in which K is the maximum carrying capacity (carrying capacity can be specified to change linearly for a number of years in a simulation, so the maximum carrying capacity can be greater than the initial carrying capacity), s is the annual environmental variation in the carrying capacity expressed as a standard deviation, and L is the specified maximum litter size. It is theoretically possible, but very unlikely, that a simulated population will exceed the calculated N_{max}. If this occurs then the program will give an error message and abort.

(4) Memory is allocated for data arrays. If insufficient memory is available for data arrays then N_{max} is adjusted downward to the size that can be accommodated within the available memory and a warning message is given. In this case it is possible that the analysis may have to be terminated because the simulated population exceeds N_{max}. Because N_{max} is often several-fold greater than the likely maximum population size in a simulation, a warning it has been adjusted downward because of limiting memory often will not hamper the analyses. Except for limitations imposed by the size of the computer memory (VORTEX can use extended memory, if available), the only limit to the size of the analysis is that no more than 20 populations exchanging migrants can be simulated.

(5) The expected mean growth rate of the population is calculated from mean birth and death rates that have been entered. Algorithms follow cohort life-table analyses (Ricklefs 1979). Generation time and the expected stable age distribution are also estimated. Life-table estimations assume no limitation by carrying capacity, no limitation of mates, and no loss of fitness due to inbreeding depression, and the estimated intrinsic growth rate assumes that the population is at the stable age distribution. The effects of catastrophes are incorporated into the life-table analysis by using birth and death rates that are weighted averages of the values in years with and without catastrophes, weighted by the probability of a catastrophe occurring or not occurring.

(6) Iterative simulation of the population proceeds via steps 7–26 below. For exploratory modelling, 100 iterations are usually sufficient to reveal gross trends among sets of simulations with different input parameters. For more precise examination of population behaviour under various scenarios, 1000 or more simulations should be used to minimise standard errors around mean results.

(7) The starting population is assigned an age and sex structure. The user can specify the exact age–sex structure of the starting population, or can specify an initial population size and request that the population be distributed according to the stable age distribution calculated from the life table. Individuals in the starting population are assumed to be unrelated. Thus, inbreeding can occur only in second and later generations.

(8) Two unique alleles at a hypothetical genetic locus are assigned to each individual in the starting population and to each individual supplemented to the population during the simulation. VORTEX therefore uses an infinite alleles model of genetic variation. The subsequent fate of genetic variation is tracked by reporting the number of extant alleles each year, the expected heterozygosity or gene diversity, and the observed heterozygosity. The expected heterozygosity, derived from the Hardy–Weinberg equilibrium, is given by

$$H_e = 1 - \Sigma(p_i^2),$$

in which p_i is the frequency of allele i in the population. The observed heterozygosity is simply the proportion of the individuals in the simulated population that are heterozygous. Because of the starting assumption of two unique alleles per founder, the initial population has an observed heterozygosity of 1·0 at the hypothetical locus and only inbred animals can become homozygous. Proportional loss of heterozygosity by means of random genetic drift is independent of the initial heterozygosity and allele frequencies of a population (assuming that the initial value was not zero) (Crow and Kimura 1970), so the expected heterozygosity remaining in a simulated population is a useful metric of genetic decay for comparison across scenarios and populations. The mean observed heterozygosity reported by VORTEX is the mean inbreeding coefficient of the population.

(9) The user specifies one of three options for modelling the effect of inbreeding: (a) no effect of inbreeding on fitness, that is, all alleles are selectively neutral, (b) each founder individual has one unique lethal and one unique non-lethal allele (Recessive Lethals option), or (c) first-year survival of each individual is exponentially related to its inbreeding coefficient (Heterosis option). The first case is clearly an optimistic one, as almost all diploid

populations studied intensively have shown deleterious effects of inbreeding on a variety of fitness components (Wright 1977; Falconer 1981). Each of the two models of inbreeding depression may also be optimistic, in that inbreeding is assumed to have an impact only on first-year survival. The Heterosis option allows, however, for the user to specify the severity of inbreeding depression on juvenile survival.

(10) Years are iterated via steps 11–25 below.

(11) The probabilities of females producing each possible litter size are adjusted to account for density dependence of reproduction (if any).

(12) Birth rate, survival rates and carrying capacity for the year are adjusted to model environmental variation. Environmental variation is assumed to follow binomial distributions for birth and death rates and a normal distribution for carrying capacity, with mean rates and standard deviations specified by the user. At the outset of each year a random number is drawn from the specified binomial distribution to determine the percentage of females producing litters. The distribution of litter sizes among those females that do breed is maintained constant. Another random number is drawn from a specified binomial distribution to model the environmental variation in mortality rates. If environmental variations in reproduction and mortality are chosen to be correlated, the random number used to specify mortality rates for the year is chosen to be the same percentile of its binomial distribution as was the number used to specify reproductive rate. Otherwise, a new random number is drawn to specify the deviation of age- and sex-specific mortality rates for their means. Environmental variation across years in mortality rates is always forced to be correlated among age and sex classes.

The carrying capacity (K) of the year is determined by first increasing or decreasing the carrying capacity at year 1 by an amount specified by the user to account for linear changes over time. Environmental variation in K is then imposed by drawing a random number from a normal distribution with the specified values for mean and standard deviation.

(13) Birth rates and survival rates for the year are adjusted to model any catastrophes determined to have occurred in that year.

(14) Breeding males are selected for the year. A male of breeding age is placed into the pool of potential breeders for that year if a random number drawn for that male is less than the proportion of breeding-age males specified to be breeding.

(15) For each female of breeding age, a mate is drawn at random from the pool of breeding males for that year. The size of the litter produced by that pair is determined by comparing the probabilities of each potential litter size (including litter size of 0, no breeding) to a randomly drawn number. The offspring are produced and assigned a sex by comparison of a random number to the specified sex ratio at birth. Offspring are assigned, at random, one allele at the hypothetical genetic locus from each parent.

(16) If the Heterosis option is chosen for modelling inbreeding depression, the genetic kinship of each new offspring to each other living animal in the population is determined. The kinship between a new animal, A, and another existing animal, B is

$$f_{AB} = 0 \cdot 5 \times (f_{MB} + f_{PB})$$

in which f_{ij} is the kinship between animals i and j, M is the mother of A, and P is the father of A. The inbreeding coefficient of each animal is equal to the kinship between its parents, $F = f_{MP}$, and the kinship of an animal to itself is $f_{AA} = 0 \cdot 5 \times (1 + F)$. [See Ballou (1983) for a detailed description of this method for calculating inbreeding coefficients.]

(17) The survival of each animal is determined by comparing a random number to the survival probability for that animal. In the absence of inbreeding depression, the survival probability is given by the age and sex-specific survival rate for that year. If the Heterosis model of inbreeding depression is used and an individual is inbred, the survival probability is multiplied by e^{-bF} in which b is the number of lethal equivalents per haploid genome.

If the Recessive Lethals model is used, all offspring that are homozygous for a lethal allele are killed.

(18) The age of each animal is incremented by 1, and any animal exceeding the maximum age is killed.

(19) If more than one population is being modelled, migration among populations occurs stochastically with specified probabilities.

(20) If population harvest is to occur that year, the number of harvested individuals of each age and sex class are chosen at random from those available and removed. If the number to be removed do not exist for an age–sex class, VORTEX continues but reports that harvest was incomplete.

(21) Dead animals are removed from the computer memory to make space for future generations.

(22) If population supplementation is to occur in a particular year, new individuals of the specified age class are created. Each immigrant is assigned two unique alleles, one of which will be a recessive lethal in the Recessive Lethals model of inbreeding depression. Each immigrant is assumed to be genetically unrelated to all other individuals in the population.

(23) The population growth rate is calculated as the ratio of the population size in the current year to the previous year.

(24) If the population size (N) exceeds the carrying capacity (K) for that year, additional mortality is imposed across all age and sex classes. The probability of each animal dying during this carrying capacity truncation is set to $(N-K)/N$, so that the expected population size after the additional mortality is K.

(25) Summary statistics on population size and genetic variation are tallied and reported. A simulated population is determined to be extinct if one of the sexes has no representatives.

(26) Final population size and genetic variation are determined for the simulation.

(27) Summary statistics on population size, genetic variation, probability of extinction, and mean population growth rate, are calculated across iterations and printed out.

Assumptions Underpinning VORTEX

It is impossible to simulate the complete range of complex processes that can have an impact on wild populations. As a result there are necessarily a range of mathematical and biological assumptions that underpin any PVA program. Some of the more important assumptions in VORTEX include the following.

(1) Survival probabilities are density independent when population size is less than carrying capacity. Additional mortality imposed when the population exceeds K affects all age and sex classes equally.

(2) The relationship between changes in population size and genetic variability are examined for only one locus. Thus, potentially complex interactions between genes located on the same chromosome (linkage disequilibrium) are ignored. Such interactions are typically associated with genetic drift in very small populations, but it is unknown if, or how, they would affect population viability.

(3) All animals of reproductive age have an equal probability of breeding. This ignores the likelihood that some animals within a population may have a greater probability of breeding successfully, and breeding more often, than other individuals. If breeding is not at random among those in the breeding pool, then decay of genetic variation and inbreeding will occur more rapidly than in the model.

(4) The life-history attributes of a population (birth, death, migration, harvesting, supplementation) are modelled as a sequence of discrete and therefore seasonal events. However, such events are often continuous through time and the model ignores the possibility that they may be aseasonal or only partly seasonal.

(5) The genetic effects of inbreeding on a population are determined in VORTEX by using one of two possible models: the Recessive Lethals model and the Heterosis model. Both models have attributes likely to be typical of some populations, but these may vary within and between species (Brewer *et al.* 1990). Given this, it is probable that the impacts of inbreeding will fall between the effects of these two models. Inbreeding is assumed to depress only one component of fitness: first-year survival. Effects on reproduction could be incorporated into this component, but longer-term impacts such as increased disease susceptibility or decreased ability to adapt to environmental change are not modelled.

(6) The probabilities of reproduction and mortality are constant from the age of first breeding until an animal reaches the maximum longevity. This assumes that animals continue to breed until they die.

(7) A simulated catastrophe will have an effect on a population only in the year that the event occurs.

(8) Migration rates among populations are independent of age and sex.

(9) Complex, interspecies interactions are not modelled, except in that such community dynamics might contribute to random environmental variation in demographic parameters. For example, cyclical fluctuations caused by predator–prey interactions cannot be modelled by VORTEX.

Discussion

Uses and Abuses of Simulation Modelling for PVA

Computer simulation modelling is a tool that can allow crude estimation of the probability of population extinction, and the mean population size and amount of genetic diversity, from data on diverse interacting processes. These processes are too complex to be integrated intuitively and no analytic solutions presently, or are likely to soon, exist. PVA modelling focuses on the specifics of a population, considering the particular habitat, threats, trends, and time frame of interest, and can only be as good as the data and the assumptions input to the model (Lindenmayer *et al.* 1993). Some aspects of population dynamics are not modelled by VORTEX nor by any other program now available. In particular, models of single-species dynamics, such as VORTEX, are inappropriate for use on species whose fates are strongly determined by interactions with other species that are in turn undergoing complex (and perhaps synergistic) population dynamics. Moreover, VORTEX does not model many conceivable and perhaps important interactions among variables. For example, loss of habitat might cause secondary changes in reproduction, mortality, and migration rates, but ongoing trends in these parameters cannot be simulated with VORTEX. It is important to stress that PVA does not predict in general what will happen to a population; PVA forecasts the likely effects only of those factors incorporated into the model.

Yet, the use of even simplified computer models for PVA can provide more accurate predictions about population dynamics than the even more crude techniques available previously, such as calculation of expected population growth rates from life tables. For the purpose of estimating extinction probabilities, methods that assess only deterministic factors are almost certain to be inappropriate, because populations near extinction will commonly be so small that random processes dominate deterministic ones. The suggestion by Mace and Lande (1991) that population viability be assessed by the application of simple rules (e.g., a taxon be considered Endangered if the total effective population size is below 50 or the total census size below 250) should be followed only if knowledge is insufficient to allow more accurate quantitative analysis. Moreover, such preliminary judgments, while often important in stimulating appropriate corrective measures, should signal, not obviate, the need for more extensive investigation and analysis of population processes, trends and threats.

Several good population simulation models are available for PVA. They differ in capabilities, assumptions and ease of application. The ease of application is related to the number of simplifying assumptions and inversely related to the flexibility and power of the model. It is unlikely that a single or even a few simulation models will be appropriate for all PVAs. The VORTEX program has some capabilities not found in many other population simulation programs, but is not as flexible as are some others (e.g., GAPPS; Harris *et al.* 1986). VORTEX is user-friendly and can be used by those with relatively little understanding of population biology and extinction processes, which is both an advantage and a disadvantage.

Testing Simulation Models

Because many population processes are stochastic, a PVA can never specify what will happen to a population. Rather, PVA can provide estimates of probability distributions describing possible fates of a population. The fate of a given population may happen to fall at the extreme tail of such a distribution even if the processes and probabilities are assessed precisely. Therefore, it will often be impossible to test empirically the accuracy of PVA results by monitoring of one or a few threatened populations of interest. Presumably, if a population followed a course that was well outside of the range of possibilities predicted by a model, that model could be rejected as inadequate. Often, however, the range of plausible fates generated by PVA is quite broad.

Simulation programs can be checked for internal consistency. For example, in the absence of inbreeding depression and other confounding effects, does the simulation model predict an average long-term growth rate similar to that determined from a life-table calculation? Beyond this, some confidence in the accuracy of a simulation model can be obtained by comparing observed fluctuations in population numbers to those generated by the model, thereby comparing a data set consisting of tens to hundreds of data points to the results of the model. For example, from 1938 to 1991, the wild population of whooping cranes had grown at a mean exponential rate, r, of 0·040, with annual fluctuations in the growth rate, SD (r), of 0·141 (Mirande *et al.* 1993). Life-table analysis predicted an r of 0·052. Simulations using VORTEX predicted an r of 0·046 into the future, with a SD (r) of 0·081. The lower growth rate projected by the stochastic model reflects the effects of inbreeding and perhaps imbalanced sex ratios among breeders in the simulation, factors that are not considered in deterministic life-table calculations. Moreover, life-table analyses use mean birth and death rates to calculate a single estimate of the population growth rate. When birth and death rates are fluctuating, it is more appropriate to average the population growth rates calculated separately from birth and death rates for each year. This mean growth rate would be lower than the growth rate estimated from mean life-table values.

When the simulation model was started with the 18 cranes present in 1938, it projected a population size in 1991 ($N \pm SD = 151 \pm 123$) almost exactly the same as that observed ($N = 146$). The large variation in population size across simulations, however, indicates that very different fates (including extinction) were almost equally likely. The model slightly underestimated the annual fluctuations in population growth [model SD (r) = 0·112 *v.* actual SD (r) = 0·141]. This may reflect a lack of full incorporation of all aspects of stochasticity into the model, or it may simply reflect the sampling error inherent in stochastic phenomena. Because the data input to the model necessarily derive from analysis of past trends, such retrospective analysis should be viewed as a check of consistency, not as proof that the model correctly describes current population dynamics. Providing another confirmation of consistency, both deterministic calculations and the simulation model project an over-wintering population of whooping cranes consisting of 12% juveniles (less than 1 year of age), while the observed frequency of juveniles at the wintering grounds in Texas has averaged 13%.

Convincing evidence of the accuracy, precision and usefulness of PVA simulation models would require comparison of model predictions to the distribution of fates of many replicate populations. Such a test probably cannot be conducted on any endangered species, but could and should be examined in experimental non-endangered populations. Once simulation models are determined to be sufficiently descriptive of population processes, they can guide management of threatened and endangered species (see above and Lindenmayer *et al.* 1993). The use of PVA modelling as a tool in an adaptive management framework (Clark *et al.* 1990) can lead to increasingly effective species recovery efforts as better data and better models allow more thorough analyses.

Directions for Future Development of PVA Models

The PVA simulation programs presently available model life histories as a series of discrete (seasonal) events, yet many species breed and die throughout much of the year. Continuous-time models would be more realistic and could be developed by simulating the time between life-history events as a random variable. Whether continuous-time models would significantly improve the precision of population viability estimates is unknown. Even more realistic models might treat some life-history events (e.g., gestation, lactation) as stages of specified duration, rather than as instantaneous events.

Most PVA simulation programs were designed to model long-lived, low fecundity (K-selected) species such as mammals, birds and reptiles. Relatively little work has been devoted to developing models for short-lived, high-fecundity (r-selected) species such as many amphibians and insects. Yet, the viability of populations of r-selected species may be highly affected by stochastic phenomena, and r-selected species may have much greater minimum viable populations than do most K-selected species. Assuring viability of K-selected species in a community may also afford adequate protection for r-selected species, however, because of the often greater habitat-area requirements of large vertebrates. Populations of r-selected species are probably less affected by intrinsic demographic stochasticity because large numbers of progeny will minimise random fluctuations, but they are more affected by environmental variations across space and time. PVA models designed for r-selected species would probably model fecundity as a continuous distribution, rather than as a completely specified discrete distribution of litter or clutch sizes; they might be based on life-history stages rather than time-increment ages; and they would require more detailed and accurate description of environmental fluctuations than might be required for modelling K-selected species.

The range of PVA computer simulation models becoming available is important because the different assumptions of the models provide capabilities for modelling diverse life histories. Because PVA models always simplify the life history of a species, and because the assumptions of no model are likely to match exactly our best understanding of the dynamics of a population of interest, it will often be valuable to conduct PVA modelling with several simulation programs and to compare the results. Moreover, no computer program can be guaranteed to be free of errors. There is a need for researchers to compare results from different PVA models when applied to the same analysis, to determine how the different assumptions affect conclusions and to cross-validate algorithms and computer code.

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Appendix. Sample Output from VORTEX

Explanatory comments are added in italics

VORTEX—simulation of genetic and demographic stochasticity

TEST *Simulation label and output file name*

Fri Dec 20 09:21:18 1991

2 population(s) simulated for 100 years, 100 runs

VORTEX first lists the input parameters used in the simulation:

HETEROSIS model of inbreeding depression

with 3·14 lethal equivalents per diploid genome

Migration matrix:

	1	2
1	0·9900	0·0100
2	0·0100	0·9900

i.e. 1% probability of migration from Population 1 to 2, and from Population 2 to 1

First age of reproduction for females: 2 for males: 2

Age of senescence (death): 10

Sex ratio at birth (proportion males): 0·5000

Population 1:

Polygynous mating; 50·00 per cent of adult males in the breeding pool.

Reproduction is assumed to be density independent.

50·00 (EV=12·50 SD) per cent of adult females produce litters of size 0

25·00 per cent of adult females produce litters of size 1

25·00 per cent of adult females produce litters of size 2

EV is environmental variation

50·00 (EV=20·41 SD) per cent mortality of females between ages 0 and 1

10·00 (EV=3·00 SD) per cent mortality of females between ages 1 and 2

10·00 (EV=3·00 SD) per cent annual mortality of adult females (2<=age<=10)

50·00 (EV=20·41 SD) per cent mortality of males between ages 0 and 1

10·00 (EV=3·00 SD) per cent mortality of males between ages 1 and 2

10·00 (EV=3·00 SD) per cent annual mortality of adult males (2<=age<=10)

EVs have been adjusted to closest values possible for binomial distribution.
EV in reproduction and mortality will be correlated.

Frequency of type 1 catastrophes: 1·000 per cent
with 0·500 multiplicative effect on reproduction
and 0·750 multiplicative effect on survival
Frequency of type 2 catastrophes: 1·000 per cent
with 0·500 multiplicative effect on reproduction
and 0·750 multiplicative effect on survival

Initial size of Population 1: (set to reflect stable age distribution)

Age	1	2	3	4	5	6	7	8	9	10	Total	
	1	0	1	1	0	1	0	0	1	0	5	Males
	1	0	1	1	0	1	0	0	1	0	5	Females

Carrying capacity = 50 (EV = 0·00 SD)
with a 10·000 per cent decrease for 5 years.

Animals harvested from population 1, year 1 to year 10 at 2 year intervals:
1 females 1 years old
1 female adults (2<=age<=10)
1 males 1 years old
1 male adults (2<=age<=10)

Animals added to population 1, year 10 through year 50 at 4 year intervals:
1 females 1 years old
1 females 2 years old
1 males 1 years old
1 males 2 years old

Input values are summarised above, results follow.

VORTEX now reports life-table calculations of expected population growth rate.

Deterministic population growth rate (based on females, with assumptions of no limitation of mates and no inbreeding depression):

r = −0·001 lambda = 0·999 RO = 0·997

Generation time for: females = 5·28 males = 5·28

Note that the deterministic life-table calculations project approximately zero population growth for this population.

Stable age distribution:

Age class	females	males
0	0·119	0·119
1	0·059	0·059
2	0·053	0·053
3	0·048	0·048
4	0·043	0·043
5	0·038	0·038
6	0·034	0·034
7	0·031	0·031
8	0·028	0·028
9	0·025	0·025
10	0·022	0·022

Ratio of adult (>=2) males to adult (>=2) females: 1·000

Population 2:

Input parameters for Population 2 were identical to those for Population 1.
Output would repeat this information from above.

Simulation results follow.

Population1

Year 10

N[Extinct] = 0, P[E] = 0·000
N[Surviving] = 100, P[S] = 1·000
Population size = 4·36 (0·10 SE, 1·01 SD)
Expected heterozygosity = 0·880 (0·001 SE, 0·012 SD)
Observed heterozygosity = 1·000 (0·000 SE, 0·000 SD)
Number of extant alleles = 8·57 (0·15 SE, 1·50 SD)

Population summaries given, as requested by user, at 10-year intervals.

Year 100

N[Extinct] = 86, P[E] = 0·860
N[Surviving] = 14, P[S] = 0·140
Population size = 8·14 (1·27 SE, 4·74 SD)
Expected heterozygosity = 0·577 (0·035 SE, 0·130 SD)
Observed heterozygosity = 0·753 (0·071 SE, 0·266 SD)
Number of extant alleles = 3·14 (0·35 SE, 1·29 SD)

In 100 simulations of 100 years of Population1:
86 went extinct and 14 survived.
This gives a probability of extinction of 0·8600 (0·0347 SE),
or a probability of success of 0·1400 (0·0347 SE).
99 simulations went extinct at least once.
Median time to first extinction was 5 years.
Of those going extinct,
mean time to first extinction was 7·84 years (1·36 SE, 13·52 SD).
123 recolonisations occurred.
Mean time to recolonisation was 4·22 years (0·23 SE, 2·55 SD).
110 re-extinctions occurred.
Mean time to re-extinction was 54·05 years (2·81 SE, 29·52 SD).

Mean final population for successful cases was 8·14 (1·27 SE, 4·74 SD)

Age 1	Adults	Total	
0·14	3·86	4·00	Males
0·36	3·79	4·14	Females

During years of harvest and/or supplementation
mean growth rate (r) was 0·0889 (0·0121 SE, 0·4352 SD)
Without harvest/supplementation, prior to carrying capacity truncation,
mean growth rate (r) was −0·0267 (0·0026 SE, 0·2130 SD)

Population growth in the simulation (r = −0·0267) was depressed relative to the projected growth rate calculated from the life table (r = −0·001) because of inbreeding depression and occasional lack of available mates.

Note: 497 of 1000 harvests of males and 530 of 1000 harvests of females could not be completed because of insufficient animals.

Final expected heterozygosity was 0·5768 (0·0349 SE, 0·1305 SD)
Final observed heterozygosity was 0·7529 (0·0712 SE, 0·2664 SD)
Final number of alleles was 3·14 (0·35 SE, 1·29 SD)

Population2

Similar results for Population 2, omitted from this Appendix, would follow.

******** Metapopulation Summary ********

Year 10

N[Extinct] = 0, P[E] = 0·000
N[Surviving] = 100, P[S] = 1·000
Population size = 8·65 (0·16 SE, 1·59 SD)
Expected heterozygosity = 0·939 (0·000 SE, 0·004 SD)
Observed heterozygosity = 1·000 (0·000 SE, 0·000 SD)
Number of extant alleles = 16·92 (0·20 SE, 1·96 SD)

Metapopulation summaries are given at 10-year intervals.

Year 100

N[Extinct] = 79, P[E] = 0·790
N[Surviving] = 21, P[S] = 0·210
Population size = 10·38 (1·37 SE, 6·28 SD)
Expected heterozygosity = 0·600 (0·025 SE, 0·115 SD)
Observed heterozygosity = 0·701 (0·050 SE, 0·229 SD)
Number of extant alleles = 3·57 (0·30 SE, 1·36 SD)

In 100 simulations of 100 years of Metapopulation:
79 went extinct and 21 survived.
This gives a probability of extinction of 0·7900 (0·0407 SE),
or a probability of success of 0·2100 (0·0407 SE).
97 simulations went extinct at least once.
Median time to first extinction was 7 years.
Of those going extinct,
mean time to first extinction was 11·40 years (2·05 SE, 20·23 SD).
91 recolonisations occurred.
Mean time to recolonisation was 3·75 years (0·15 SE, 1·45 SD).
73 re-extinctions occurred.
Mean time to re-extinction was 76·15 years (1·06 SE, 9·05 SD).

Mean final population for successful cases was 10·38 (1·37 SE, 6·28 SD)

Age 1	Adults	Total	
0·48	4·71	5·19	Males
0·48	4·71	5·19	Females

During years of harvest and/or supplementation
mean growth rate (r) was 0·0545 (0·0128 SE, 0·4711 SD)
Without harvest/supplementation, prior to carrying capacity truncation,
mean growth rate (r) was −0·0314 (0·0021 SE, 0·1743 SD)

Final expected heterozygosity was 0·5997 (0·0251 SE, 0·1151 SD)
Final observed heterozygosity was 0·7009 (0·0499 SE, 0·2288 SD)
Final number of alleles was 3·57 (0·30 SE, 1·36 SD)

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