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Abstract: A recently drafted Master Plan developed by the cheetah propagation group of the Species Survival Plan of the American Association of Zoological Parks and Aquarium has listed basic research in reproduction as a primary end of the SSP. This research is to be conducted by NOAHS Center scientists and will include: (1) fundamental studies of the reproductive physiology, and endocrinology of the species; (2) assessing, understanding and combating infertility; (3) germ plasma storage of sperm, and embryos for conservation and biodiversity; and (4) artificial breeding strategies including in vitro fertilization and artificial insemination. Considering the combined results of the genetics, physiology, structure and natural history of the captive population of the cheetah there are several recommendations that are important to improve the demographic pattern: First, the outbreeding of individuals within the captive population, second, the increasing of the breeding population's size and finally, the continually increasing of the research on captive and free-ranging cheetahs.

FOCUS ON THE CHEETAH:

TECHNICAL INNOVATIONS IN SPECIES CONSERVATION

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Introduction

Today many of our world's wildlife species are endangered and threatened with extinction. Already there are several species which are extinct in the wild and survive today only under managed breeding programs in zoological parks and wildlife reserves.

Established on behalf of endangered species, the National Zoo's Center for New Opportunities in Animal Health Sciences or NOAHS, is applying the recent advances in biomedical sciences in three areas; genetics, reproductive physiology and veterinary medicine, to the ever-worsening crisis in wildlife conservation. NOAHS Center builds on years of research in the human and domestic animal sciences and applies the knowledge gained to the conservation of endangered species.

NOAHS mission is to develop and employ a comprehensive program of modern biological technologies in two important areas: the management and propagation of critically endangered species; and the maintenance of genetic diversity in captive and free-ranging populations.

NOAHS objectives are: (1) To research and apply advanced biomedical technologies in genetics, reproduction physiology and veterinary medicine to the breeding and maintenance of populations of endangered species; (2) To increase the understanding of the biology of wildlife species by examining free-ranging animals in their native habitat; (3) To train scientists, graduate students and post graduate

students who will become the new generation of dedicated and innovative conservation bioscientists with a multidisciplinary perspective; and (4) To rapidly disseminate information through publication.

Collaboration between research scientists Dr. Mitch Bush, Chief Veterinarian and Dr. David Wildt, Reproductive Physiologist both from the National Zoo; Dr. Stephen O'Brien, Geneticist from the National Cancer Institute; and myself, Cheetah Breeding Specialist and Studbook Keeper for the Cheetah, led to the idea for NOAHS Center. We began working together almost a decade ago to explore the question; Why do cheetahs have problems breeding in captivity?

We found that the cheetah lacks genetic variation. The consequences of this genetic uniformity have lead to reproductive abnormalities, high infant mortality, and a weakened immune system which has lead to disease susceptibility.

In order to discuss the biomedical technologies that are now available in species conservation and relate the use of these technologies to the cheetah, it is important to give an overview of what we now know about this species.

Origins

The cheetah is an endangered species and the fastest of all land animals which can reach speeds of over 70 miles per hour. The cheetah dates back to prehistoric time, about 3.5 million years, well before the lion or the leopard. It was one of the most widely distributed of all land mammals and roamed the entire world. Through fossil remains, it is thought that the cheetah actually originated here in North America, and through the course of time migrated over

land bridges from North America to China, through Asia, into India and then into Africa (Adams, 1979). The cheetah that roamed the earth at that time was a giant cheetah, about 2 to 3 times larger than the present day cheetah and could run just as fast as it's present day form (Wrogemann, 1975).

The cheetah of today evolved to it's present form about 200,000 years ago, and was living in it's entire worldwide range as recent as 20,000 years ago. It is significant that cheetah emerged as a distinct species at a time in our evolutionary history when grasslands were rapidly spreading and taking over forests, and the gazelles, a suitable prey animal for the cheetah, became prominent. A complementary arrangement whereby predator and prey evolved simultaneously. (Wrogemann, 1975)

Adaptations for Speed

In obtaining speeds of up to seventy miles per hour in pursuit of its prey, the cheetahs respiratory rate climbs from 60 to 150 breaths per minute during its high speed chase. Because of the increased rate, the cheetah can only run a few hundred yards before collapsing, at this time, it is extremely vulnerable to predators who might not only steal it prey, but attack it as well. It is not an aggressive animal, having a light and lanky body, very weak jaws and small teeth, the price it paid for it's speed.

The cheetah is aerodynamically built for speed and is unmatched in the animal and automotive world for its acceleration from zero to 40mph in just three strides, and full speed in a matter of a few seconds. A stride for a running cheetah is about 20 feet, and only one foot touches the ground at a time, and there are two points in

their stride where there is no contact with the ground, when they are fully extended and then when they are all the way doubled up (Hildebrand, 1959). The cheetah has specialized for this speed through many morphological and physiological adaptations: To facilitate such explosive use of energy, the cheetah is endowed with a powerful heart; and oversized liver; large strong arteries; small head; enlarged nostrils, and large eyes; a narrow light weight body; long, slender legs; specialized muscles for high acceleration, giving greater reach to the legs; the hip and shoulder girdles swivel on a spine that curves up and down as the limbs are alternately bunched up and then extend when running; and a muscular tail that acts as a stabilizer or rudder for balance. It is the only member of the cat family with semi non-retractable claws which are used like cleats for traction when running. No other species of cat can run like a cheetah. Nor does any other cat look or behave just like this early offshoot from the main stream of feline evolution. It is the most specialized of all the 37 species of felids worldwide (Nowak, et al, 1983; Kingdon, 1978).

The cheetah was first described by Schreber in 1776, and classified under the cat family, Felis. Because of the number of differences in the anatomy of the cheetah which distinguish it from the other cats, these differences led to its being accorded its own genes, Acinonyx, by Brooks in 1828 (Kingdon, 1978).

The Revered Cheetah

The cheetah's history with humans dates back at least 4,000 years. During the time of the pharaohs, their praise of the animal went so far that they believed, that since the cheetah was the fastest land animal, it would carry their spirits away after death. Statues

of cheetahs have been found in the royal tombs of the pharaohs. The cheetah was important in many of the native tribes: The Bushman ate the meat to obtain speed, Zulu kings wore their skins for dignity, and witch doctors used the bones of the feet of the cheetah for fleet footedness (Wrogemann, 1975).

They have been called the Spotted One or "Chita" in Hindu, and are know as the hunting leopard, the most easily tamed of the big cats. They have been kept by kings, emperors and princess and were considered to be a prerequisite for royalty, almost as long as the possession of gold. The best records of the cheetah being kept as hunting leopards are from the 14th, 15th and 16th centuries. The emperors kept as many as 1000 cheetahs in their stables at one time. With this great number of cheetahs in captivity, it was recorded only once, by Abkar the Great in the 15th century, that a litter was ever born (Guggisberg, 1975). All these cheetahs that were kept as hunting leopards were taken out of the wild breeding populations. The numbers began declining throughout Asia, and in the early 1900, India and Iran began importing cheetahs from Africa for hunting purposes.

Modern History

It is evident that cheetah have inhabited this planet for a very long while. The history suggests that although they inhabited a wide range of territory, they were never abundant in number. The trend today is towards even fewer cheetah due to the steady, and in some areas, rapid elimination of habitats tolerable to this species. In recent history, much of the total range of the cheetah has been swamped by livestock, since man and his livestock prefer the grassland vegetation, the type of habitat where cheetah would usually have been

found. These agricultural developments and new settlements have played havoc with the cheetahs habitat.

Today the cheetah is nearly extinct in Asia and India with perhaps only a small population of a few hundred left in Iran, U.S.S.R. and Afghanistan. The population in Africa is between 10,000 and 20,000 animals. Because of their swift and elusive character, it is difficult to obtain exact demographics. Free-ranging cheetahs presently inhabit a broad section of central, eastern and southern Africa. Although the area of the cheetahs range is vast, population density estimates are rather low (estimates at less than one animal per 6km), which has raised the possibility that cheetah density in certain areas is lower than the ecosystem could support (Frame and Frame, 1981; Myers, 1975).

The two strong holds of cheetah are in eastern and southern Africa, primarily Kenya, Tanzania, and South West Africa/Namibia. In Kenya, the largest populations of cheetahs are found in the vast arid and semi-arid rangelands in the northern part of the country which support a large gazelle population. Large scale poaching operations are also found in this area, and cheetah skins are said to be more common now than ever. Lack of proper funds make it hard to protect this vast territory (Marker, 1985; Parker, 1988).

National parks and private game reserves are conservation areas where the cheetah is afforded protection from human encroachment. But, the population of cheetah in these areas of East Africa has been hindered by tourist vans and cars which often times interrupt an attempted stalk or a kill. Cheetah numbers in these parks are also relatively low due to the direct competition from the growing populations of lions, hyenas and other large predators. The cheetah

is the best hunter on the savannahs, and other predators are waiting to steal their prey. The cheetah looses about one half of it's kills each year to other predators. Since the cheetah is not an aggressive animal, it will leave a kill when harassed. This strong competition among other predators has put enormous pressure on the cheetah in protected reserves.

Namibia has the largest remaining wild population of cheetah. Here it is in direct competition with man and his livestock. Cheetah predation on livestock is of significant economic loss to the ranchers, and unless the rancher is willing to accept the financial losses, the cheetah is removed either by live capture or by the accepted practice of shooting them. In 1982, 890 cheetahs were shot, 875 in 1983, 715 in 1984, 650 in 1985, and 271 in the first six months of 1986 (Morsbach, 1987). During the past few years, the cheetah population in Namibia has dropped drastically from about 6,000 in 1974 to perhaps as low as 2,000 or 3,000 in 1987 (Morsbach, 1987), and the population continues to decline (Morsbach, 1989). The critical concern for the cheetah in Namibia now is not only the rancher but the political pressures on the country which will be undergoing independence over the next year. With all the other problems of this developing country, the cheetah is likely to be forgotten about and possibly may perish before our eyes.

Political pressure and the consequent governmental legislation in countries dealing with the cheetah, whether wild or captive, plays an important role in the preservation of the species.

The Cheetah in Captivity

The first cheetah exhibited in a zoological setting was at the

Zoological Society of London in 1829. Most other major European zoos began exhibiting the species in the 1850's. The first cheetahs exhibited in North America was in New York's Central Park Zoo in 1871. However, the cheetah was rarely seen in North American zoo's until the end of World War II. After 1945 the cheetah was exhibited in many European and North American zoos, with the majority of the animals coming from Kenya and later Somalia. Due to a decline in the East African cheetahs in the early 1960's virtually all of the wild caught cheetahs in zoo today have come from Namibia (Marker, 1983).

Even though the cheetah has been exhibited in zoos since the early 1800's, the first documented birth did not occur until 1956 at the Philadelphia Zoo. The next litter followed at the Krefeld Zoo in Europe in 1960, Oklahoma City Zoo in 1962, and at Whipsnade, London in 1967. This sporatic pattern of captive births continued until the early 1970's when an increase in productivity took place (Marker 1983).

A summary of the numbers of imports and captive births in North America since 1871 is presented in Table 1. In total, 485 cheetahs have been imported into North America and there have been 493 captive births, from 134 litters in over 57 zoological facilities (Marker, O'Brien, 1989).

The population growth presented in Figure 1 consists of at least three parameters; imports, captive births, and death. The changes in these three characters of the population are shown as a function of time in Figure 2. Examination of this figure shows that the majority of the increase in the captive cheetah population before 1972 can be attributed to imports. During the 1956-1972 period, there were 305 wild-caught imports, and only a few captive births (n=21). Importation of cheetah was terminated by the passage of the Endangered

Species Act in 1973. This created the necessity of developing captive breeding programs in the United States to maintain the captive cheetah population.

The growth pattern of a population is actually derived from the combination of both reproduction and relative survival. As shown in Figure 2, cheetah mortality gradually increased over the 30 year study period, clearly correlating with population growth (Fig.1) The timing of death in the cheetah population, revealed some marked trends. First, the incidence of infant mortality before age 6 months (table 2) was 37%, a rather high value compared to other non-inbred zoo species (Marker, O'Brien, 1989; O'Brien et al., 1985; Ralls and Ballou, 1982a,b; Ralls et al., 1979). Secondly, the most vulnerable age of death is infancy (0-1 month) when the mortality is 10 times the frequency than any other age (table 2). During the last three decades, the success in breeding cheetahs has been relatively poor. The pedigree of the 194 cheetahs living in North America by the end of 1986 is presented in Figure 3. Of the 349 wild-caught cheetahs that were imported, 52 (14.8%) reproduced and 33 of these have living descendants(presented in Figure 3). Among the 417 captive-bred offspring, 257 survived to reproductive age. Of this later group, 35 (13.6%) have successfully bred (Marker, O'Brien 1989).

Despite the large number of founders compared to other breeding programs, relatively few have made a disproportionately large contribution to the gene pool. For example, from 1981 to 1985, 27 cheetahs reproduced, but 10 of these animals produced two-thirds of the offspring. These 27 animals in four years have produced a total of 149 cubs that represents 31% of the cubs born over an entire 30

year study period (Marker, O'Brien, 1989).

The experience of North American zoological facilities has reaffirmed the traditional difficulty in captive propagation of the cheetah. Despite the capturing, rearing and public display of cheetahs for thousands of years, the first documented captive breeding of cheetahs did not occur until 1956. By 1974, a population of over 200 animals had been achieved and is currently maintained by a combination of imports and captive breeding. The breeding program, however is not self sustaining, and in the absence of further imports, the size of the captive population would be expected to decline further. The North American captive population as of December 31, 1988 was, 197 animals in 43 facilities, and the captive world population is nearly 650 animals (Marker-Kraus, 1989).

Research Findings

The difficulty in captive breeding of the cheetah prompted a rather extensive genetic and physiological analysis of both captive and free-ranging cheetahs (O'Brien et al, 1985). The cheetah appears to be unique among felids and other mammals in having an extreme paucity of genetic variation as estimated by electrophoretic surveys of allozymes and cell proteins resolved by two-dimensional gels (O'Brien et al., 1983). More unusual was the observation of allogenetic skin grafts acceptance among unrelated cheetahs, revealing genetic monomorphism at the major histocompatibility complex (MHC), an abundantly polymorphic locus in nearly all mammals (O'Brien, et al, 1985). A comparative analysis of cheetah ejaculates revealed a sperm count one-tenth of that observed in domestic cats and an extremely high frequency (71%) of morphological spermatozoal abnormalities. (Wildt et al., 1983, 1987). In addition to these phenotypic

observations, patterns of skeletal variation also show significant asymmetry of bilateral characters, a phenomenon generally common in inbred animals (Wayne et al, 1986). The combined genetic, reproductive and morphological data placed the cheetah in a situation reminiscent of deliberately inbred mice or livestock and prompted us to hypothesize that in its recent history the species had probably suffered a demographic contraction or bottleneck necessarily followed by inbreeding . Based on the genetic and physiological similarities of the southern and eastern African subspecies, we concluded that the proposed bottleneck was an ancient one, perhaps dating back to the global mammalian extinctions near the end of the Pleistocene over 10,000 years ago (O'Brien et al, 1985; 1987).

Consequences of Genetic Uniformity

The fact that genetic uniformity poses a threat to the survival of a population or a species has been evident since Darwin formulated his theorem of natural selection. Genetic variation is the raw material for evolution; it is genetic heterogeneity on which natural selection operates in times of environmental or ecological change. Evolutionary theory predicts that a species with little genetic plasticity would be particularly vulnerable in a time of ecological perturbation, and a graphic demonstration that this is so for the cheetah has occurred. Feline infectious peritonitis (FIP), a fatal coronavirus disease, has been reported in several cheetah facilities throughout the world (Marker, O'Brien, 1989). The extensive documentation of an epizootic outbreak of FIP at Wildlife Safari, in Oregon, where 90% of the population showed clinical signs of the virus and 48% of the population died (O'Brien et al., 1985; Pfeifer at al.,

1983; Evermann et al., 1986), alerted the wildlife veterinary community to the extremes of morbidity that this disease can cause in cheetahs. The morbidity of FIP in cheetahs can be explained by monomorphism of genes within the MHC sublocus. The MHC contains immune-response genes. A population that becomes monomorphic at the MHC would be particularly vulnerable to a viral strain able to circumvent the immunological defenses, therefore, any virus that adapts to one animal's immune-surveillance system would subsequently find every other system it encounters in the population to be identical to the first and therefore easy to get around.

Management Recommendations

Considering the combined results of the genetics, physiology, structure and natural history of the captive population of the cheetah there are several recommendations that are important to improve the demographic pattern. First, outbreeding individuals within the captive population. This strategy could be extended by the introduction of new animals of different genetic lineages, perhaps most importantly the East African with the South African. Secondly, the breeding population may be typically low because of inherent genetic impoverishments, the only way to reverse decline may be to increase the size of the breeding population. Increasing the captive population is needed so as not to impact on the remaining free-ranging population. The development of the International Cheetah Studbook (Marker-Kraus, 1989) will allow population managers to make better recommendations for possible breeding partners from around the world. Also the animals being captured in habitats where cheetahs are legally hunted and trapped like Namibia, should be brought into the captive breeding populations.

Finally, increased research on captive and free-ranging cheetahs should continue. A recently drafted Master Plan developed by the cheetah propagation group of the Species Survival Plan of the American Association of Zoological Parks and Aquariums has listed basic research in reproduction as a primary end of the SSP. This research is to be conducted by NOAHS Center scientists and will include: (1) Fundamental studies of the reproductive physiology, and endocrinology of the species; (2) Assessing, understanding and combating infertility; (3) Germ plasm storage of sperm, and embryos for conservation and biodiversity; and (4) Artificial breeding strategies including in vitro fertilization (IVF) which NOAHS researchers have developed for the domestic cat, and artificial Insemination (AI). This plan has defined research goals in the related fields of reproduction, including; behavior, genetics, nutrition, pathology and epidemiology. The anticipated results may provide the key to stabilizing the world - wide captive population with the ultimate end of release of captive-bred animals to suitable natural habitats.

This multidisciplinary approach to the conservation of endangered species is the objective of the National Zoo's NOAHS Center.

Conclusion

The cheetah it seems is a survivor, and we hope with help and sound management it can recover from its decreasing gene pool. In the past it survived natural bottlenecks on its own, although with great loss of variability. Now it is going through an un-natural bottleneck and it will take concerned and knowledgeable intervention by people, using biomedical technology to keep cheetahs on earth for the future.

The cheetah has long been associated with man, but their history

is one of decline. Time is running out for this cat. If we are prepared to face and tackle the problems, to concede to the cheetah its place in the sun, we may yet save from extinction this creature so regal and aloof, so beautiful and lithe in movement a symphony of natural grace.

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Table 1. History of Captive Cheetahs in North America

	1871-1913	1914-1926	1926-1955	1956-1986	1987-1988
No. Imported	14	0	71	385	15
No. Births	0	0	0	417	76
No. Deaths	9	4	54	566	70
No. Zoological Facilities	4	1	13	39	43
No. Alive at end of period	5	1	19	193	197

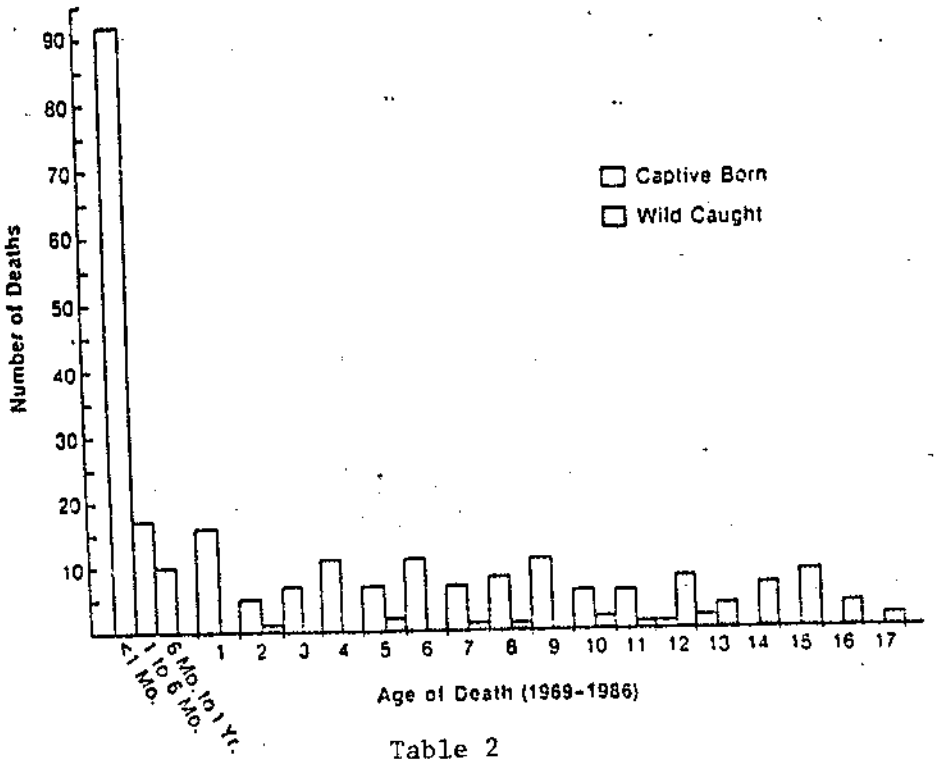


Table 2

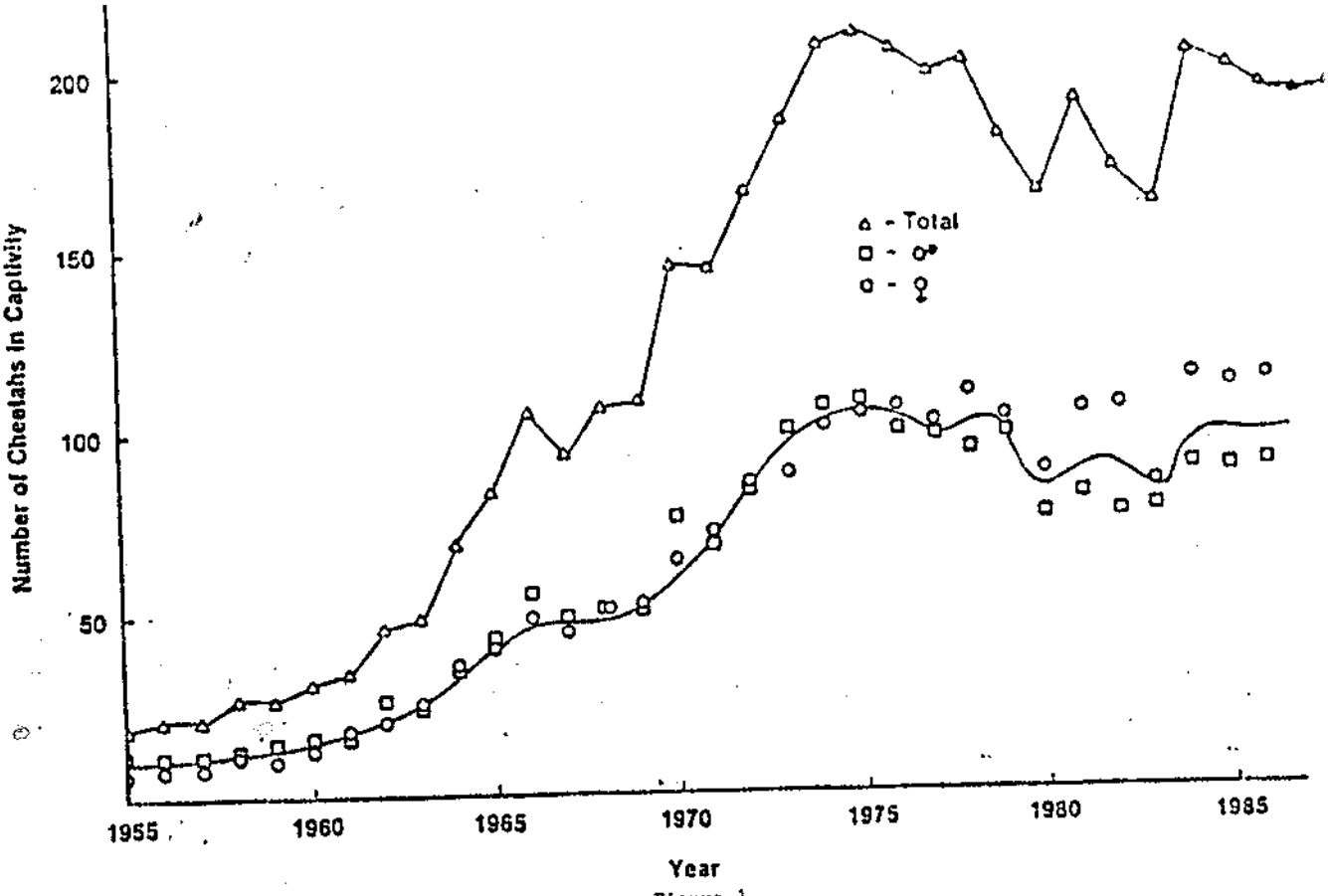

Number of Cheetahs in Captivity
200
150
100
50
1955
1960
1965
1970
1975
1980
1985
Year
△ - Total
□ - ♂
○ - ♀

Figure 1

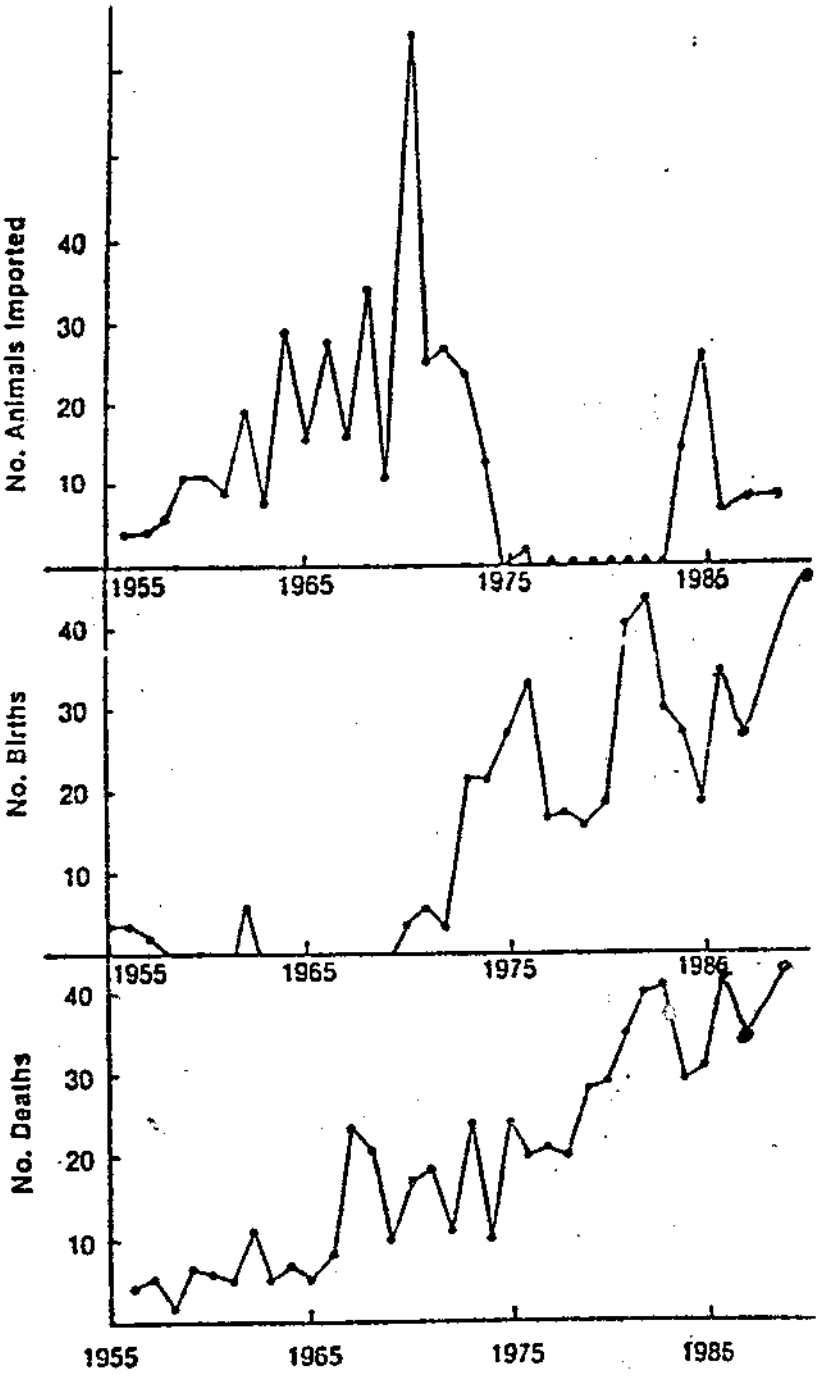
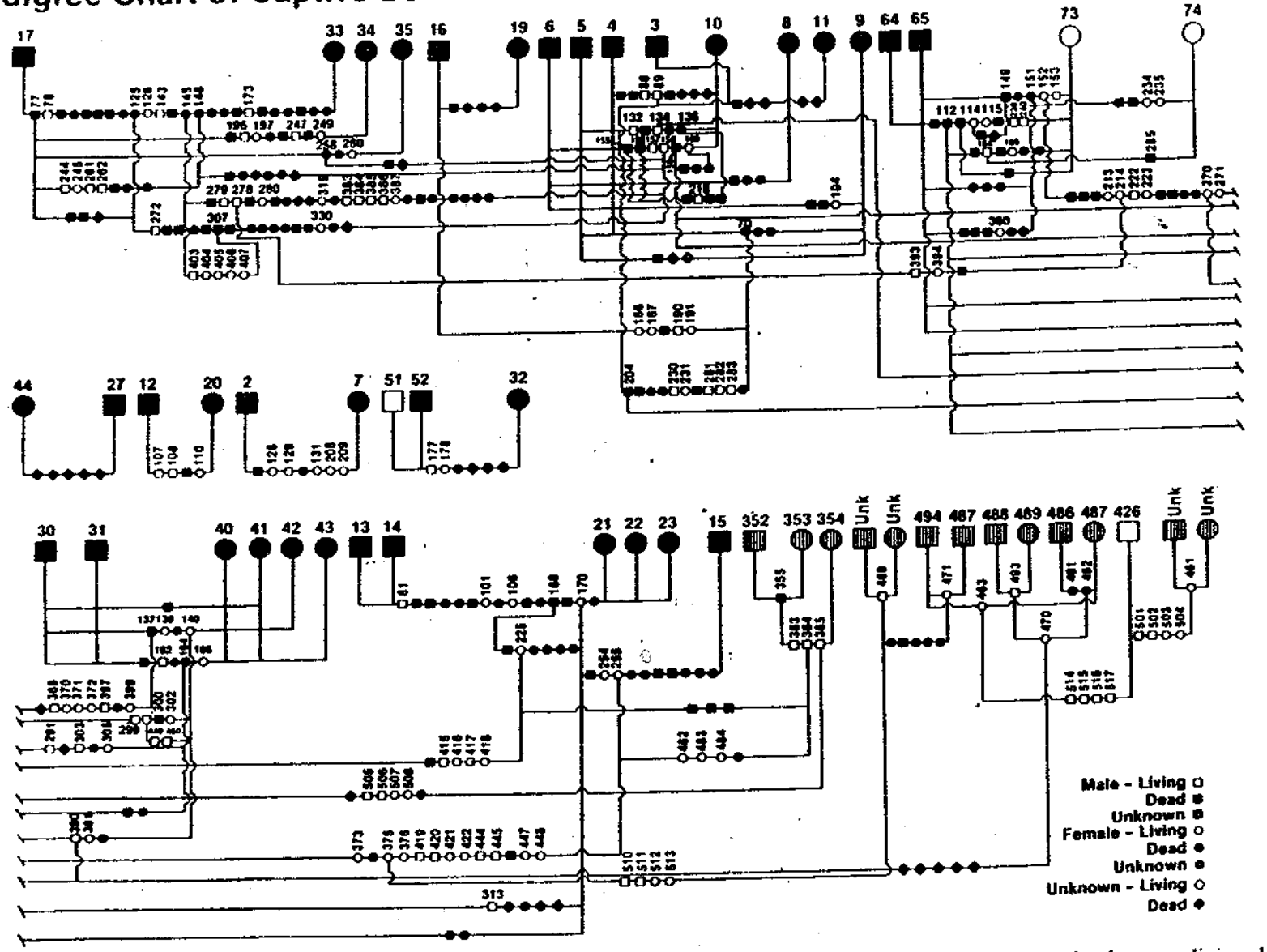

No. Animals Imported
40
30
20
10
1955
1965
1975
1985
No. Births
40
30
20
10
1955
1965
1975
1985
No. Deaths
40
30
20
10
1955
1965
1975
1985
Year

Figure 2

Figure 3

Pedigree Chart of Captive Born Cheetahs in North America (31 December, 1986)



Pedigree of North American captive-born cheetahs in U.S. zoos in 1986. Not included are 10 successful breeders that have no living descendants. Solid figures are deceased. Nos. are *North American Regional Cheetah Studbook* nos. [Marker, 1986]. (□) ♂; (○) ♀.