The Mandate for Research in Zoos

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Too little is known of our precious wildlife. Many species are on the verge of extinction, and if steps are not taken soon to preserve them, a vast storehouse of information will be lost forever. Who knows what benefits to mankind will never be realized nor understood, as man himself goes about destroying species after species. How long will it take to break the necessary chain which allows all species to live together harmoniously on this planet?

Zoological parks are becoming the last stronghold for species' survival. Geneticists, virologists, and physiologists, to name just a few disciplines, work against unbelievable odds to try to preserve some of the most severely endangered: pygmy chimpanzee, cheetah, rhinoceros, and Przewalski's horse, among others. However, zoological gardens are not wealthy, and governmental and private agencies are not willing to provide the funding essential to support research endeavors needed to save just a few, and preserve their biological qualities.

Soemmering's gazelles originating in Somalia, have not been doing well in captivity. A group imported from Khartoum and kept at Hanover Zoo, FRG, from 1958 to 1971 has died out, necessitating importation of two new pairs in 1982. In the United States, this gazelle has been kept mainly at Busch Gardens, Tampa, Florida. However, the excessive perinatal mortality, around 50%, has prevented establishment of a self-sustaining population. In 1972 some of Busch Gardens' herd was acquired by the San Diego Zoo and placed at its spacious Wild Animal Park. Despite the Zoo's superb breeding record with numerous gazelline species, success with Soemmering's gazelles was not forthcoming, and only three specimens of a larger stock remain. What is wrong? What might be the reasons for the poor success with this species? Autopsies disclose no uniform causes, no anomalies or contagion that might be held responsible, and the very scant literature on this taxon is of no help. Indeed, little is known about this species, which may well fall victim to strife or a famine-ridden North Africa.

This scenario could be written for many a species that finds itself at the verge of extinction; too little is known of our precious wildlife, and knowledge may never be gathered in time to establish self-sustaining populations before the range and habitat are forever lost. This is the reason for the plea to establish strong research efforts on behalf of vanishing species. While one might justify such research with the hope that it would give information that ultimately could be useful to man, its applied results should be the overriding motivation. The implications of the findings of intensive research are unforeseeable.

To explore the example of Soemmering's gazelles further, let me hypothesize that the poor results may have a chromosomal basis. Some years ago we were interested in the nature of antilopine chromosomes, their number and structure, and found that many of the species possessed an X-to-autosome translocation.' This is not a common feature among mammalian taxa, and to explain this X/A translocation, a common ancestor to these forms was suggested. As a result of this translocation, these species then have different chromosome numbers in the two sexes: males have one unpaired, additional chromosome. For instance, the related Grant's gazelles posses 2n = 39 in the male and 2n = 38 in the female. The same is true of all the other species with X/A translocation we have studied - for example, Dama gazelle, *Gazella dama*, 2n = 40[M], 39[F]; Speke's gazelle, *Gazella spekei* 2n = 33[M],32[F]. Moreover, the chromosome number in those species with translocations was found to be considerably lower than those species that lack this translocation - for instance, Thomson's gazelle, *Gazella thomsoni*, 2n = 58.

Soemmering's gazelle was not available during these earlier investigations, but we have recently studied 8.20 (8 male, 20 female) specimens, with bewildering findings.[2] Not only was the chromosome number variable (2n = 34 to 39), but the structure of chromosomes, occasioned by variable so-called Robertsonian translocations, was so different that none of the eight males had identical chromosomes, and 12 different types of sets were found amongst the females. (A 'translocation' of chromosomes in this context is meant to be the fusion of chromosomes; it preserves the genetic content, but rearranges its order. A Robertsonian translocation is the fusion of two acrocentric elements at their centromeres, thus producing a metacentric chromosome, a frequent evolutionary process). We have no good explanation for this extraordinary finding, but we are convinced that efforts at breeding a species with such a variable genotype are unlikely to meet with permanent success. No other example of the kind exists in other mammalian taxa, particularly not in a species with such uniform phenotype and restricted geographic distribution.

The point to be made is that no reason existed to suspect that a chromosomal variability might be the cause of the species' poor reproductive success. Indeed, from a cytogeneticist's point of view, these results are of great interest *per se*, but ultimately they may have considerable application for the management of an endangered species in captivity. It is difficult to imagine how we can hope to undertake successful breeding *without* having this basic biological knowledge at hand, a point so frequently made in medical research. ‘The cost of *not* doing research’[3] is amply documented in human medicine, but for zoo species Hediger's 1969 exclamation[4] still stands: ‘However galling it may be. . . it has to be admitted that scientific research is usually placed last in zoological gardens, if indeed it has any place at all.’ It has a place, all right, but its execution is minuscule. Let us trace briefly the research efforts that do exist.

RESEARCH IN ZOOS—BRIEF HISTORY

The need for scientific exchange has long existed in the world of zoos. This need is met reasonably successfully by the International Zoo Yearbook, produced by the London Zoo since 1959. On a more practical and disease-oriented level are the annual meetings and reports on zoo animal diseases which originated in 1958 with the Tierpark Berlin East and which the Tierpark has continued to organize. Research in zoos has also been the topic of several special meetings, the first of which took place in San Diego in 1967.[5] In 1965 the late Walter van den Bergh celebrated the 125th anniversary of the Antwerp Zoo with a study of zoo research,[6] and the theme of the 60th annual meeting of the American Association of Zoological Parks and Aquariums (AAZPA) was the stimulation of zoo research.

It is, of course, not true that zoo research has existed only in recent years. The contents of the volumes just cited testify to a diversified activity more than 20 years ago. But this research was sporadic, often undertaken by scientists living outside the zoo community, and, particularly in continental Europe, it was often accomplished through affiliations with universities and veterinary schools. Hediger,[4] in particular, had strongly advocated such relationships. By necessity then, these activities were casual, often extremely practical and truly applied. What was missing was research of a more basic nature and executed by zoo personnel.

The first step in this direction occurred in London when the Wellcome and Nuffield foundations placed institutes within or next to the London Zoological Garden in 1964 and 1965. These two institutes have recently been combined under the leadership of Dr John Hearn and comprise a substantial group of basic scientists from different disciplines. A formal research department became an integral part of the San Diego Zoo in 1975. The Cincinnati and Columbus zoos in Ohio also have organized investigative units, while many other parks (National Zoo, Washington, DC; Los Angeles Zoo; and particularly some East German zoos) have a variety of scientists in their employ. Special mention must be made of the very substantial investigative efforts made by the New York Zoological Society. Believing that the time for wildlife study in the natural habitat is limited but its conduct essential, this Society has espoused more field research and active support for local conservation than any other zoo.

This list looks impressive on first sight until it is recognized that the studies encompass a vast number of species: mammals, birds, amphibia, and insects as well as botanical topics. The ignorance of the basic biological qualities of so many forms is so profound that the perhaps 200 investigators toiling in these laboratories can only scratch the surface. This situation is particularly deplorable when it is realized that time will not permit a full understanding of the many larger species now facing extinction. Many are not kept in captivity or if they are, these are too few to allow intensive study. The Sumatran or Javan rhinoceros, the only recently discovered giant peccary of the Chaco and the monkey-eating eagle are a few such spectacular species.

The potential loss of never-gained information is inestimable. It is for this reason that Hediger's plea for the conduct of scientific research in zoos is here reiterated. It seems mandatory that governments, agencies, and zoos, indeed the general public, become concerned and demand that such activities be undertaken forthwith and on a substantial scale. The budget of zoos cannot afford what is regarded a luxury -support of scientific investigations. At the same time, they cannot afford not to undertake research. The following account will review some of the insights gained through the activities of the Zoological Society of San Diego and the applicability to conservation efforts; it will also evaluate the benefit of zoological collections in general. The list can be lengthened at will by citing advances made in other parks or research in progress now. The result is a resounding affirmation of the necessity of in-house research in zoos.

PATHOLOGY

The San Diego Zoo has performed consecutive autopsies on all animals for over 20 years and has on file (currently being computerized) 22 000 autopsies on exotic species. Not only is the collection a rich source of comparative material for visiting scientists, its rapid retrievability often allows inclusion of diseases in the differential diagnosis of sick animals and has allowed recognition and correction of untoward conditions, nutritional deficiencies, sources of infection and the like. The originator of the program, L. A. Griner, has summarized the first 12 000 autopsies in a novel text, *'Pathology of Zoo Animals'*,[7] which proves helpful to other institutions. Three examples will suffice to highlight the importance of this discipline.

Hanuman Langurs and Acacia Leaves

When in 1981 three Hanuman langurs (*Presbytis entellus)*, succumbed to perforations of stomach or intestines, a detailed search for this unusual cause of death was instituted. The complex gastric arrangement of leaf-eating monkeys had been well recognized,[8] and these primates had been given a primarily leafy diet, readily available in San Diego. Collaboration with botanists from the University of California at Davis allowed identification of the cause of perforation, the spines of *Acacia salignum,* with which the langurs had been fed.[9] With elimination of this plant from their diet this cause of mortality has also been eliminated.

Ring-tailed Lemur and Toxoplasmosis

When a ring-tailed femur *(Lemur catta)* was found to have died of disseminated toxoplasmosis, an inquiry into the source of infection was instituted. A group of reproductively active femurs had lived in a large, planted cage for some time. All were bled with controls from other cages, but only the former possessed antibodies. Cats, well known for their ability to transmit this disease, had no access to the cage, and both groups ¢f animals had received similar diets. It was found, however, that Seriemas, South African grassland birds, had recently been introduced into the cage and were regularly fed raw meat, another known source of toxoplasma organisms. Their removal stopped further toxoplasmosis, and it is assumed that scraps of meat ingested by the femurs caused the disease

Hemosiderosis

Hemosiderosis of liver and Iymphoreticular organs of a variety of animals, especially some birds, had occasionally been seen. However, when it was found to be associated with several cases of hepatoma and choledochocystadenocarcinoma in femurs, more attention was paid to the finding. A systematic review of the pathologic findings in several femur species yielded surprising results.[10] A variety of congenital anomalies and widespread hemosiderosis were found, and the recognition of obstructive intestinal hairballs led to regular administration of lubricants (Petromalt).[11] Black femurs *(Lemur macaco)* and ruffed femurs (*Varecia variegata),* were more severely affected than ring-tailed femurs *(Lemur catta)* despite similar diets, and all adults had some degree of hepatic and Iymphoreticular hemosiderosis; this was found as early as one year of age.

Because freshly imported adults did not have the iron accumulation and because the duodenal mucosa was the most strikingly pigmented tissue, a dietary source was suspected. First, we installed water filters, but this had no effect. Next, an iron incorporation study of young femurs and rhesus monkeys was undertaken; the results showed no significant difference in the avidity for iron in the two species,[12] at least in youth. Currently, we are experimenting with low-iron biscuits in a controlled study, but we have so far failed to discover whether the rich source of iron in monkey biscuits and/or a special propensity of femurs for iron absorption is the cause of iron storage. Not only is the resolution of this problem significant for the endangered femurs, it also has great medical significance inasmuch as the precise mechanism for the maintenance of an appropriate iron balance in man is not understood, and there is no appropriate animal model for hemochromatosis.

VETERINARY RESEARCH

European zoos have more traditionally been associated with veterinary schools, and zoos are more often headed by professionals of that discipline than is true in the United States. In the us part-time veterinarians often looked after the health of the varied collection and more or less learned 'on the hoof' about different species' varied requirements. The Philadelphia Zoo under Ratcliffe was an early exception. Here, the Penrose Laboratory, founded in 1901, engaged in serious studies of tuberculosis as well as other infections, and notable contributions were made to the understanding of the nutritional requirements of zoo species. Their studies have had significant impact on other zoos in the USA as have their publications and symposia.[13]

With the Endangered Species Act of 1973 and the greater difficulty of acquiring animals over the past 15 years, veterinary care has become more important. Most zoos have acquired at least one full-time veterinarian, several have started postdoctoral specialized training programs, and a professional Society of Zoo Veterinarians has been founded with its own *Journal of Zoo Animal Medicine.* This much enhanced activity has culminated in the establishment of Specialty Boards in 1984 and in numerous conferences and texts.[14] Thus, a new discipline has evolved that has taken professional charge of animal care, but has also added significantly to the strain on already taxed budgets. Nevertheless, it is widely considered essential, and the following random examples will make its importance comprehensible.

At the San Diego Zoo a Bornean orang-utan that had been a very prolific breeder in the past lost weight and lost interest in sexual activity. Sedation and anesthesia followed - veterinary procedures that not only require specialized skills but also need to be tailored to the individual species, and have evolved extensively in recent years. Upon examination of the animal a deep tooth abscess, penetrating into the nasal cavity, was the only significant finding. With the help of an interested dentist this abscess was drained and a root canal filling applied, restoring the animal to its former self.[15] Tooth decay, abscesses, broken teeth and other anomalies were identified thereafter in many species, and a regular dental program was instituted for all species. At the same time, the findings called into question a number of feeding practices and led to an active browse-feeding program. Tigers, elephants and all sorts of primates and carnivores were the beneficiaries, as could have been anticipated had the text by Colyer been known.[16]

Douc langurs *(Pygathrix nemaeus)* are without question the most colorful and spectacular primates in existence. At the same time these Vietnamese leaf-eating monkeys are delicate and, with the exception of the Cologne and San Diego zoos, have all but disappeared from exhibition, with little hope of their return. How essential it is then to have self-sustaining colonies with adequate reproduction. A cough was noticed in the San Diego Zoo colony, and when an animal was autopsied, destructive lung disease due to a widespread lung mite *(Pneumonyssus simicola)* was found. In other species such as rhesus monkeys this pulmonary disease was less severe. but no therapy instituted in the past had been effective. Because of the precious nature of these animals, a study was undertaken to find ways of eradicating the mite. Ivermectin, donated by Merck Co. before its official approval, proved to be effective in control of the infection in rhesus monkeys,[17] and, as a result, all of our douc langurs, treated with a single injection of this potent agent, can now look forward to freedom from lung disease. At the same time the drug was found to be effective against a host of other recalcitrant parasites.

The Zoological Society of San Diego has a Wild Animal Park, where large numbers of ungulates roam in unusually large enclosures. Breeding is abundant; for instance, over 50 white rhinoceros and 100 Arabian oryx have been bred in 10 years. Surely this operation does much to perpetuate wildlife in captivity under semi-natural conditions. Because of its success, it has been possible to reintroduce Arabian oryx into its native countries.

Excess breeding leads to the need to remove offspring to other zoos, and catching wary animals in a difficult terrain has been an enormous task for the veterinary staff. They have developed the strategy of removal of newborns since they are easily caught and identified daily by headcounts. However, it was found that the newborn nursery suffered from significant epidemics of diarrhea in overcrowded periods. A collaborative effort between the university and zoo microbiologists and veterinarians identified infection with *Cryptosporidia* as the major problem.[18] Regular cow colostrum feeding was instituted during the first months of the neonates' life, and survival has much improved, making this practice worthwhile.[19]

These are but superficial insights into the benefits zoos can derive from expert veterinary care and research. Doubtless many changes will occur in the future of this discipline, with sub-specialization, better instrumentation for early diagnosis (for example, ultrasound) and institution of rapid-oscillation anesthesia, particularly for large animals.

ENDOCRINOLOGY

Basic reproductive patterns and the hormones by which these are determined are similar in all mammals. In fact, reptiles and birds, too, rely upon the same steroid hormones. The details of reproductive cycles, feedback messages from embryo to maternal organism and placental performance, however, differ widely in different taxa, work that has yet to be charted for most species. And yet, great hope is placed in embryo transfer to surrogate mothers of less endangered species and in the routine incorporation of artificial insemination in the breeding program of exotic species. Fundamental studies are required before wider use can be made of the successful experience with domestic species and others, such as gaur into cow[20] banteng into cow,[21] Przewalski's horse into domestic horse,[22] bongo into eland[23] and insemination of gorilla[24] and giant panda. To furnish this background information we have undertaken systematic studies, relying largely on waste materials (urine and feces) rather than blood, to ascertain hormone levels and to develop methodologies that can be widely applied. The following examples will suffice as demonstrations of the applicability of the findings to zoo management of exotic species.

It is estimated that some 30% of exotic birds are monomorphic -- that is, their sex cannot be ascertained visually. Numerous examples of inappropriate pairing can be cited, and amateur parrot breeders are aware of this problem. In some instances the cytogenetic demonstration of ZZ for male and ZW for female sex chromosomes is practical, and this is done routinely in the rescue program for the severely endangered California condor. In some birds intense behavioral studies may distinguish sexes, and sex can also be ascertained by laparoscopy, a widely practiced veterinary approach. Nevertheless, there are many small birds and severely endangered species for which these techniques are less applicable. Systematic inquiry showed that birds excrete conjugated gonadal steroids in their feces whose amounts during adulthood reveal the sex. In particular, the fecal sex determination discriminates readily between males and females when expressed as the ratio of estrogen to testosterone. Males are below 2, females generally above 2.[25] The technique has proven its usefulness, especially in pairing the severely threatened Puerto Rican parrot,[26] and more recently it has been found that it can determine the sex of hatchlings from the waste remaining in the shell.[27]

Similarly effective is the measurement of sex steroids in the urine of mammals. It can be used in a wide variety of circumstances, and the variable concentration of urines is readily overcome when the results are indexed by creatinine. Contrary to expectations, it was learned that the total estrogen excretion in gorillas during pregnancy is an order of magnitude lower than in man and orangutan,[28] which has obvious implications for the monitoring of precious pregnancies. It has allowed the determination of cycles in the Indian rhinoceros, among many other species, with the delineation of abnormalities in sterile females.[29] For purposes of mate introduction or artificial insemination (AI) the technique can anticipate the time of ovulation and has been streamlined so that it has become a practical tool, similar to that used in human medicine.

Induction of ovulation in cows is accomplished with prostaglandins, but other species, such as the horse, are resistant to this management. Carnivores in particular have been difficult to manage in this respect. The realization in recent years that the hypothalamic hormones, especially GnRh (gonadotropin-releasing hormone), have a pulsatile release pattern has led to a simulation of the pattern experimentally. Implantation of osmotic pumps that alternately release peanut oil and hormone in dogs, cheetahs and other species has led to estrus and successful ovulation with offspring when other methods failed.[30]

These examples clearly show that basic endocrine physiologic research is highly applicable to zoo management, and one can confidently expect that its significance will increase as captive reproduction becomes more important.

CYTOGENETICS

On the surface, it might appear that cytogenetic investigations had little relevance to the management of endangered species, but the remarks made at the outset on Soemmering's gazelle should convince otherwise. Let us add a few more examples.

When it became apparent that Przewalski's horse had 66 chromosomes instead of the 64 presented by all races of domestic horse,[31] this proved to be essential knowledge for the future breeding of this species, now extinct in the wild. It had been known that one line of this horse, bred in various zoological parks, had been contaminated by the blood of an infamous domestic mare at Halle[32] in East Germany. Moreover, it was found that hybrids (2n=65) of these species are fertile.[33] This has not settled the controversy about keeping the two lines of Przewalski's horse separate, but it has given some additional scientific basis for this contention.

Muntjacs, or barking deer, from Formosa *(Muntiacus recuesi)* and India *(Muntiacus muntjak)* look essentially alike, and it was thus startling to find that the former species has 46 chromosomes while the latter has six (female) or seven (male) elements, albeit giant ones.[34] Indian muntjac chromosomes have since become interesting objects of scientific study. The recognition of this remarkable discrepancy in chromosome number led to the postulation that intermediate species must exist, some of which have since been identified.[35] In general, however, the insight into this cytogenetic divergence has raised many genetic problems that are gradually being addressed. One of these is the remarkable fact that animals with such different chromosome sets can produce viable, albeit sterile, hybrids.[36]

The slow methodology of detailed cytogenetic studies and re-exploration of specimens when new techniques are developed has led to the creation of a large liquid-nitrogen storage facility at San Diego in which cells can literally be stored into perpetuity. It can be called the 'Ark of the 20th Century', for it is certain that cell lines of many species, their DNA and other attributes, will in the future be available only through such stores.

GENETICS

A small founding population of animals brings a restricted number of genes into captivity and, with the inbreeding that necessarily follows, deleterious genes will be concentrated. Genetic heterogeneity, however, is beneficial for the survival of animals and in its ability to adapt to changing circumstances. A particular result of inbreeding is what has been termed inbreeding depression, the loss of overall fitness, particularly with respect to successful reproduction. This sort of ill-adaptation has been witnessed in a variety of captive animals already[37] and is particularly well known in children of incest.[38] When mice are intentionally inbred in an attempt to produce specific strains of mice it has been the experience that a large proportion of mice dies out from the concentration of lethal genes. It is obviously of interest to avoid such mishaps in attempts at creating self-sustaining populations of endangered species by careful management. In order to be effective in this effort it is essential that more genetic knowledge be accumulated than is presently available.

Just how interesting genetic studies in exotic species can be, may be highlighted by the following example. There are two acknowledged subspecies of white rhinoceros, the Southern, *Ceratotherium simum simum,* and the Northern, *Ceratotherium simum cottoni,* the former being reasonably plentifiul since the rescue operation by Col. John Vincent, Ian Player and others in 1965, and the exceptional breeding results at San Diego's Wild Animal Park. The northern variety, however, has shrunken to an estimated 11 specimens in the wild[39] and a handful in captivity. Having stored tissues from a dead specimen, we undertook mitochondrial DNA fragment comparisons between these two rhinoceros forms and a black rhinoceros. It was found that the two white rhinoceros forms differed markedly as a result of mutational substitutions, which, by analogy with other data, suggested their separation two million years ago.[40] This finding heightened the desirability of international efforts to bring the remaining specimens into captivity lest they become extinct through poaching - a task yet to be completed

Similar studies on dried muscle from the extinct quagga, proving its relationship to the plains zebra,[41] further emphasizes the need to preserve specimens for genetic analysis with techniques that are bound to become even more powerful in the future.

Perhaps the most important practical management tool for zoo operation has been the computerization of pedigree data. Commencing with the creation of international studbooks for endangered species and international registration of zoo animals (ISIS), the ability to mate least related animals through the help of computer programs is the most effective way of keeping inbreeding to a minimum.[42] In the future, this ability combined with the prospect of AI through frozen semen shipped between zoos, rather than the expensive shipping of valuable animals, will aid the establishment of self-sustaining populations of rare exotic species appreciably. While we have a long way to go in this respect, the foundations have been laid.

BEHAVIOR

This discipline has a long record in zoo research. Because unusual animals could be observed without cumbersome, expensive field trips and because of the unobtrusiveness of the discipline, necessitating no handling of animals, behavioral observations of exotic species have been made in most zoos. This has often led to an improvement of the conditions in which animals are kept, their boredom could be relieved to an extent, and comparative data (among similar species and relating them to man) could be collected. It must be realized, however, that often the zoo conditions do not simulate the natural environment of free-ranging specimens, and caution has to be applied when sweeping conclusions are drawn, particularly when strict adherence to methodologies of sampling and statistical evaluation is lacking. Nevertheless for the management of zoo animals, expert behavioral information can be of great value, as the few examples to follow will amplify.

A major problem of captive species, particularly of primates, is boredom, the lack of proper socialization and apparent 'rejection' of newborn infants. The consequence has been the rearing of infants in nurseries or children's zoos, where the diapered youngsters are a delight for zoo visitors (and cash flow). Little was it realized, however, that such human-reared infants grow up to become asocial animals, misfits that are of little use in a breeding program. Thus, numerous individuals of endangered species were prevented from making their genetic contribution to the population.

We have worked especially with the sorely pressed lion-tailed macaque *(Macaca silenus),* a handsome species from India, where agriculture is encroaching upon its habitat. Over the years, we have collected from other institutions numerous adults whose early experience prevented them from becoming socialized. A variety of techniques have been used in attempts to introduce these males and females to the large troupe of macaques we maintain, but all have failed. We are collecting their semen (perhaps ova in the future) in order not to lose their genetic contribution, and we are concentrating on assuring normal social development by keeping and mixing larger troops of lion-tailed macaques. When, as recently happened, a mother died from cryptococcosis soon after giving birth and the infant had to be reared artificially, it was possible to reintroduce the infant to the group gradually before it was 3 months old. It was then firmly adopted by an older female. Past experience had shown that there is a critical period (about three months) after which such reintroduction cannot be expected to succeed.

The breeding of cheetahs *(Acinonyx jubatus)* has not been easy for most zoos, and only a few have successfully raised many generations of this species. The cheetah is a remarkable animal in other ways. Detailed genetic inquiry into wild and captive cheetah-s undertaken recently has shown they possess virtually no genetic heterogeneity.[43, 44] But this is unlikely to be the reason for their difficult reproduction in zoos, as it applies also to wild cheetahs. Rather, it is suspected that the solitary nature of this species causes problems in reproduction when, as is usual, animals are exhibited in the zoo in pairs. Long-term observation was necessary to ascertain that males should be kept separate from females (visually, auditorily and probably olfactorily) until the latter come into estrus. When this does not occur naturally, it can be induced by GnRh pumps, as mentioned above. Of course, estrous behavior needs to be recognized by detailed observations that rely on prior charting of the animals' behavioral repertoire. Adhering to such management procedures allows the reproduction of cheetahs to proceed.

It was learned in the course of time, however, that several cheetahs suffered from severe rhinitis and that it was a sequel of palatal perforation. Rather than assuming this to be a genetic trait, we studied cheetahs raised on different diets and learned that only those receiving the macerated, boneless meat diet often fed to carnivores had perforations. Animals fed on bones, whole carcasses and the like had normal palates.[45] Apparently, the chewing and tearing exercise of the normal cheetah kill (the 'hassle factor' as our dentist used to call it) prevents the overgrowth of the lower molars that causes the perforation. Of course, we have since switched to other diets.

MICROBIOLOGY

Studies of the usual bacterial causes of diseases are routine aspects of veterinary care in most zoos, even though unusual organisms are encountered. It is inexplicable, for instance, why so many diverse species in our zoo suffer from cryptococcosis (among them, proboscis monkey, koala, cheetah, and lion-tailed macaque) when immune deficiencies are not apparent, nor are great concentrations of this fungus recognized in the environment. Likewise; parasitic infections present an ever-present problem to all zoos, and freedom from~worms and many unusual parasites is 4 dream that may never be achieved. Least well understood, however, are the viral diseases of the many species in captivity.

Often their viral etiology is only an inference made from pustules or manifestations identified at autopsy, for the isolation of viruses is rarely attempted and, even if it is, often unsuccessful. Yet viruses are present and may even present a threat to humans, as is best exemplified by the lethal (to humans) herpes virus of rhesus monkeys. That other viruses may spread amongst different species when kept together in herds, such as at San Diego's Wild Animal Park, would appear to be likely but needs investigation.

This fear of the introduction of contagions from foreign countries is, of course, the reason for severe restrictions on importation of those species (ungulates) that may bring in viruses which could spread among domestic livestock with disastrous consequences. Among these are the viruses of hoof-and-mouth disease, blue tongue, and hog cholera, to name a few of a long list that prevent importation of animals from many countries. It must be realized that these are only the recognized agents. New viruses are often discovered in inapparent human carriers and one must suspect that the same may hold true of exotics - namely, that they harbor viruses as yet unrecognized but potentially harmful. Furthermore, this discipline (virology) should in future be able to answer the question of whether fertilized ova or semen, appropriately frozen, can be safely imported from areas with endemic disease so as to bring in the proverbial 'new blood' for zoos.

A few relevant examples of our studies should suffice to emphasize just how important virus research is or should be for the management of exotic species in zoos.

Malignant catarrhal fever (MCE) of ruminants is a well-recognized disease caused by a herpes virus. In Africa it has been learned by experience that during the migration of wildebeests, when birthing occurs, many exposed tribal cattle die of the disease.[46] This has led tribesmen to remove their cattle if possible. In several zoological parks the sporadic outbreak of malignant catarrhal fever has caused the death of a variety of precious specimens, notably gaur, even though there was no apparent source of the virus.

In order to conduct appropriate tests, the virus had first to be isolated and propagated in tissue culture (a feat not yet accomplished for the sheep-associated MCF), its pathogenicity proven by infecting test animals, and reliable antibody screening method developed. When this was accomplished, screening of stocks could proceed. It turned out that the likely source of viruses in zoos was the wildebeest, for all individuals showed significant titers. But many other species, notably alcelaphinae, showed susceptibility and titers.[47] The ubiquity of the virus in asymptomatic gnus poses a significant problem for zoos, since most hold these species and often house them alongside other susceptible species. Since vaccination against herpes viruses is at present a dim prospect, reasoning by analogy from the human situation, it now becomes important to demonstrate just how the virus is spread from placenta, by direct contact or by vectors.

Snow leopards (*Uncia uncia)* and other large carnivores are known to suffer frequent hepatic disease, for example cirrhosis.[48-50] Recent studies showed a nearly ubiquitous infection of these animals with a hepatitis virus that is similar in many respects to the human hepatitis B virus.[51] The virus can be isolated from blood and grown in culture, and it is being characterized, with the ultimate hope of vaccination of uninfected animals. Just how the virus is transmitted is uncertain, but investigations should eventually lead to better management procedures. When one realizes how slow the progress of combating the equivalent human disease has been, despite the untold number of scientists addressing this problem, it is small wonder that it has not been solved for felines, where only one laboratory concerns itself systematicallv with the disease.

GENERAL PHYSIOLOGY

The examples given in the section on endocrinology indicated that physiological principles revealed by that discipline can be of use to captive exotic species, as well as in the framework of the science of comparative biology. Of course, this is not limited to endocrine parameters: other systems have similar contributions to make. Thus, comparative studies in nutrition are essential - witness the very varied gastrointestinal morphology (and inferred physiology) of many mammals, and the necessity for vitamin D_3 (as opposed to D_2 in human beings) in South American monkeys, among many pragmatic examples that have been investigated at least superficially.

If this knowledge is minuscule in mammals kept in zoos, it is even sparser for reptiles. Not only are the principles of mammalian physiology derivable from medical and veterinary studies less applicable, but reptiles are also less accessible to investigators and more difficult to keep. It is shocking to learn, for instance, that 60,000 green iguanas are imported into the Uniited States annually, but that after one generation in captivity virtually no reproduction occurs. It is therefore not surprising that the interesting Komodo dragon, despite its longevity, has never been bred outside Indonesia, although hope has frequently been expressed and well-meant changes in cage designs have been executed. With the conviction that the situation will not change until a better understanding of the physiology of the species is gained, we have initiated studies to address at least some of the problems.

Studies of thermoregulation with intestinal probes in zoo-kept Komodo dragons (*Varanus komodoensis)* revealed considerably greater physical activity in Indonesia than had been observed elsewhere. It quickly became obvious that zoo-kept animals in colder climates use most of their food intake to produce body heat. This was so despite the widespread use of heat lamps, the ubiquitous red lamps so often seen in zoos, particularly at night. Their body heat was literally being drained into the cool cement floor or other common substrates found in conventional zoo designs. A simple aluminum waterbedlike structure was constructed, which, it turns out, is not only considerably less expensive to heat but allows the animals to choose an optimal spot to rest upon.[52] But simple as this seemed, it turned out that many other species benefitted from this new cage design, with the result that carnivores were able to litter successfully for the first time and many primates find more comfortable refuge on cool nights. Moreover, it appears to be a practical source of warmth for pig-raising in cooler climates, where exposure to cold has led to excessive losses.

Nutritional problems often afflict reptiles in captivity, with growth retardation and deformities a frequent result. The need to supply maternal intestinal microorganisms to young iguanas has recently been recognized,[53] but this is not always the answer to complex apparent deficiencies. Consequently, investigators have recently composed an artificial diet of defatted beef hearts, packaged in intestines, and affectionately designated ‘Wonder Wienies’[54] for its superior quality in promoting health and growth in a variety of reptiles. While efficient, it hides the fact that little is known about the principal metabolic needs of many taxa.
Also poorly understood are the physiological signals for reproduction in reptiles. While temperature and nutrition - particularly avoidance of stunting in youth - are doubtless prime requirements, a better understanding of the dependency on light cycles through the third eye and,

perhaps, melatonin secretion is badly needed. That iguanas can be brought into sexual receptivity has recently been demonstrated with the abdominal implantation of GnRh pumps, but we are a long way from the physiological understanding that will allow the intentional breeding of large tortoises and Komodo dragons in zoo conditions.

EPILOGUE

There is little doubt that the rate of extinction of animals and plants all over the world is rapidly increasing. Larger animals, those that we customarily expect to see in zoos, might be regarded as surrogates by which we perceive the numerous smaller species and plants that depart this globe uncharted and unknown because of a burgeoning human population and the consequent habitat destruction. Ultimate conservation, of course, would require drastic and worldwide population control, and cessation of man's incursions into primeval habitats. These objectives, while the most noble of goals, are not the topic of this essay.

I have reviewed the role that zoos may play in the conservation of those larger species, who, by virtue of their size, their demands for space or their special attributes, such as the rhinoceros' horn, the elephant's tusk or the cheetah's hide, are the most vulnerable and also the most visible members of a declining diversity of biota. For self-preservation alone, zoos should do their utmost to enhance breeding in order to cease their dependency on new importation. And, of course, this has recently become the cornerstone of modern zoological parks, the creation of self-sustaining populations of animals. For long-term success, though, much more basic information must be acquired about exotic species, and that is one reason for a mandate of zoo research. Another poignant reason is that with extinction an enormous amount of potentially valuable information will be lost -witness the results of DNA research on quagga and northern white rhinoceros.

We owe it to science - indeed to our successors and our children - to conduct these studies, at the very least to conserve the genomes as well as currently possible. It is recognized that zoos may only be halfway houses on the road to extinction, that the efforts are stopgap in nature. But the studies are now feasible and the cost of doing this research is less than the cost of not doing it. National and international agencies should strive to support it, rather than investing most of their resources in man's health. As Chief Seattle so superbly exclaimed 'What is man without the beast?'[55] Extinction is now largely caused by man,[56] and the 'New Zoo' must be envisaged as the ultimate preserver of endangered species.[57]

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